(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
14 March 2002 (14.03.2002)

PCT

(10) International Publication Number
WO 02/20287 A1

(51) International Patent Classification[7]: B60C 23/02

(21) International Application Number: PCT/US01/28010

(22) International Filing Date: 7 September 2001 (07.09.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/231,378	8 September 2000 (08.09.2000)	US
60/269,415	16 February 2001 (16.02.2001)	US
60/291,511	16 May 2001 (16.05.2001)	US
60/304,013	9 July 2001 (09.07.2001)	US

(71) Applicant: AUTOMOTIVE TECHNOLOGIES INTERNATIONAL, INC. [US/US]; P.O. Box 8, Denville, NJ 07834 (US).

(72) Inventors: BREED, David, S.; 48 Hillcrest Road, Boonton Township, NJ 07005 (US). JOHNSON, Wendell, C.; Suite 100, 2675 Junipero Avenue, Signal Hill, CA 90806 (US). DUVALL, Wilbur, E.; 57 Northwoods Drive, Kimberling City, MO 65686 (US). CASTELLI, Vittorio; 2577 Somerston Road, Yorktown Heights, NY 10598 (US). SEITZ, William, E.; 23 Pembroke Way, Bedford, NH 03100 (US).

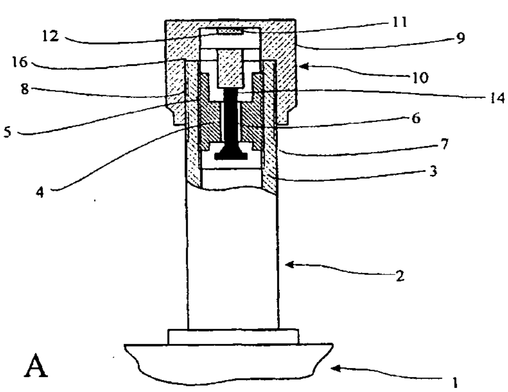
(74) Agent: ROFFE, Brian; 366 Longace Avenue, Woodmere, NY 11598-2417 (US).

(81) Designated States *(national)*: DE, GB, JP.

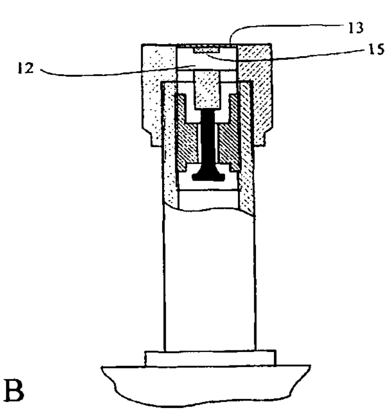
Published:
— *with international search report*

[Continued on next page]

(54) Title: VEHICLE WIRELESS SENSING AND COMMUNICATION SYSTEM



A



B

(57) Abstract: Valve cap (10) for monitoring pressure and/or temperature of a tire (1) having a valve stem (2) including a valve assembly (5) having a valve pin (6). A body (9) of the valve cap (10) mates with the valve stem (2) and defines a chamber (12) upon such mating. A valve pin depressor (14) is arranged in the body (9) and depresses the valve pin (6) upon mating of the body (9) with the valve stem (2) to open the valve assembly (5) and enable flow communication between an interior of the tire (1) and the chamber (12). At least one SAW sensor (11) is arranged in the chamber (12) for receiving a signal and returning a signal modified by virtue of the temperature and/or pressure of the tire (1).

WO 02/20287 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Vehicle Wireless Sensing and Communication System

Field of the invention

The invention relates to the field of vehicular sensor systems and more particularly, to the field of wireless sensing and communications for a vehicle.

Background of the invention

The invention is related to the monitoring of vehicular components, systems and subsystems as well as to the measurement of physical and chemical characteristics relating to the vehicle or its components, systems and subsystems and using the measurements to control and/or affect one or more vehicular system. Some of the systems which are monitored include the tires,

With respect to monitoring of the tires, such monitoring is extremely important because NHTSA has recently linked 148 deaths and more than 525 injuries in the United States to separations, blowouts and other tread problems in Firestone's ATX, ATX II and Wilderness AT tires, 5 million of which were recalled in 2000. Many of the tires were standard equipment on the Ford Explorer. Ford recommends that the Firestone tires on the Explorer sport utility vehicle be inflated to 26 psi, while Firestone recommends 30 psi. It is hard to believe that a tire can go from a safe condition to an unsafe condition based on an under inflation of 4 psi.

Recent studies in the United States conducted by the Society of Automotive Engineers show that low tire pressure causes about 260,000 accidents annually. Another finding is that about 75% of tire failures each year are preceded by slow air leaks or inadequate tire inflation. Nissan, for example, warns that incorrect tire pressures can compromise the stability and overall handling of a vehicle and can contribute to an accident. Additionally, most non-crash auto fatalities occur while drivers are changing flat tires.

Tire failures are clearly a serious automobile safety problem that requires a solution.

About 16% of all car accidents are caused as a result of incorrect tire pressure. Thus, effective pressure and wear monitoring is extremely important. Motor Trend magazine stated that one of the most overlooked maintenance areas on a car is tire pressure. An estimated 40 to 80 percent of all vehicles on the road are operating with under-inflated tires. When under-inflated, a tire tends to flex its sidewall more, increasing its rolling resistance which decreases fuel economy. The extra flex also creates excessive heat in the tire that can shorten its service life.

The Society of Automotive Engineers reports that about 87 percent of all flat tires have a history of under-inflation. About 85% of pressure loss incidents are slow punctures caused either by small-diameter objects trapped in the tire or by larger diameter nails. The leak will be minor as long as the nail is trapped. If the nail comes out, pressure can decrease rapidly. Incidents of sudden pressure loss are potentially the most dangerous for drivers and account for about 15% of all cases.

A properly inflated tire loses approximately 1 psi per month. About 35 percent of the recalled Bridgestone tires had improper repairs.

Research from a variety of sources suggests that under-inflation can be significant to both fuel economy and tire life. Industry experts have determined that tires under-inflated by a mere 10% wear out about 15% faster. An average driver with an average set of tires can drive an extra 5,000 to 7,000 miles before buying new tires by keeping the tire properly inflated.

The American Automobile Association has determined that under inflated tires cut a vehicle's fuel economy by as much as 2% per psi below the recommended level. If each of a car's tires is supposed to have a pressure of 30 psi and instead has a pressure of 25 psi, the car's fuel efficiency drops by about 10%. Depending on the vehicle and miles driven that could cost from $100 to $500 a year.

The ability to control a vehicle is strongly influenced by tire pressure. When the tire pressure is kept at proper levels, optimum vehicle braking, steering, handling and stability are accomplished. Low tire pressure can also lead to damage to expensive tires and wheels.

A Michelin study revealed that the average driver doesn't recognize a low tire until it's 14 psi too low. One of the reasons is that today's radial tire is hard to judge visually because the sidewall flexes even when properly inflated.

Despite all the recent press about keeping tires properly inflated, new research shows that most drivers do not know the correct inflation pressure. In a recent survey, only 45 percent of respondents knew where to look to find the correct pressure, even though 78 percent thought they knew. Twenty-seven percent incorrectly believed the sidewall of the tire carries the correct information and did not know that the sidewall only indicates the maximum pressure for the tire, not the optimum pressure for the vehicle. In another survey, about 60% of the respondents reported that they check tire pressure but only before going on a long trip. The National Highway Traffic Safety Administration estimates that at least one out of every five tires is not properly inflated.

The problem is exacerbated with the new run-flat tires where a driver may not be aware that a tire is flat until it is destroyed. Run-flat tires can be operated at air pressures below normal for a limited distance and at a restricted speed (125 miles at a maximum of 55 mph). The driver must therefore be warned of changes in the condition of the tires so that she can adapt her driving to the changed conditions.

One solution to this problem is to continuously monitor the pressure and perhaps the temperature in the tire. Pressure loss can be automatically detected in two ways: by directly measuring air pressure within the tire or by indirect tire rotation methods. In the case of indirect detection, various methods are based on the number of revolutions each tire makes over an extended period of time through the ABS system and others are based on monitoring the frequency changes in the sound emitted by the tire. In the direct detection case, a sensor is mounted into each wheel or tire assembly, each with its own identity. An on-board computer collects the signals, processes and displays the data and triggers a warning signal in the case of pressure loss.

Under-inflation isn't the only cause of sudden tire failure. A variety of mechanical problems including a bad wheel bearing or a "dragging" brake can cause the tire to heat up. In addition, as may have been a contributing factor in the Firestone case, substandard materials can fail causing intra-tire friction and a buildup of heat. The use of re-capped truck tires is another example of heat caused failure as a result by intra-tire friction. An overheated tire can fail suddenly without warning.

As discussed in more detail below, tire monitors, such as those disclosed below, permit the driver to check the vehicle tire pressures from inside the vehicle.

The Transportation Recall Enhancement, Accountability, and Documentation Act, (H.R. 5164, or Public Law No. 106-414) known as the TREAD Act, was signed by President Clinton on November 1, 2000. Section 12, TIRE PRESSURE WARNING, states that: "Not later than one year after the date of enactment of this Act, the Secretary of Transportation, acting through the National Highway Traffic Safety Administration, shall complete a rulemaking for a regulation to require a warning system in a motor vehicle to indicate to the operator when a tire is significantly under-inflated. Such requirement shall become effective not later than 2

years after the date of the completion of such rulemaking." Thus, it is expected that a rule requiring continuous tire monitoring will take effect for the 2004 model year.

This law will dominate the first generation of such systems as automobile manufacturers move to satisfy the requirement. In subsequent years, more sophisticated systems that in addition to pressure monitor temperature, tire footprint, wear, vibration, etc. will be installed on vehicles. Although the Act requires that the tire pressure be monitored, it is believed by the inventors that other parameters are as important as the tire pressure or even more important than the tire pressure as described in more detail below.

Consumers are also in favor of tire monitors. Johnson Controls' market research showed that about 80 percent of consumers believe a low tire pressure warning system is an important or extremely important vehicle feature. Thus, as with other safety products such as airbags, competition to meet customer demands will soon drive this market.

Although, as with most other safety products, the initial introductions will be in the United States, speed limits in the United States and Canada are sufficiently low that tire pressure is not as critical an issue as in Europe, for example, where the drivers often drive much faster.

The advent of microelectromechanical (MEMS) pressure sensors, especially those based on surface acoustical wave (SAW) technology, has now made the wireless and powerless monitoring of tire pressure feasible. This is the basis of the tire pressure monitors described below. According to a Frost and Sullivan report on the U.S. Micromechanical Systems (MEMS) market (June 1997): "A MEMS tire pressure sensor represents one of the most profound opportunities for MEMS in the automotive sector. "

Prior to discussing the invention, some prior art will be discussed.

There are many wireless tire temperature and pressure monitoring systems disclosed in the prior art patents. For example, reference is made to U.S. Pat. Nos. 4,295,102, 4,296,347, 4,317,372, 4,534,223, 5,289,160, 5,612,671, 5,661,651, 5,853,020 and 5,987,980 and International Publication No. WO 01/07271(A1), all of which are illustrative of the state of the art of tire monitoring.

Devices for measuring the pressure and/or temperature within a vehicle tire directly can be categorized as those containing electronic circuits and a power supply within the tire, those which contain electronic circuits and derive the power to operate these circuits either inductively, from a generator or through radio frequency radiation, and those that do not contain electronic circuits and receive their operating power only from received radio frequency radiation. For the reasons discussed above, the discussion herein is mainly concerned with the latter category. This category contains devices that operate on the principles of surface acoustic waves (SAW). The disclosure discussed below is concerned primarily with SAW devices.

International Publication No. WO 01/07271 describes a tire pressure sensor that replaces the valve and valve stem in a tire. It is a dual chamber device and is thus more complex then the present invention. The system of this invention does not use a pressure chamber.

U.S. Pat. No. 5,231,827 contains a good description and background of the tire-monitoring problem. The device disclosed, however, contains a battery and electronics and is not a SAW device. Similarly, the device described in U.S. Pat. No. 5,285,189 contains a battery as do the devices described in U.S. Pat. Nos. 5,335,540 and 5,559,484. U.S. Pat. No. 5,945,908 applies to a stationary tire monitoring system and does not use SAW devices.

One of the first significant SAW sensor patents is U.S. Pat. No. 4,534,223. This patent describes the use of SAW devices for measuring pressure and also a variety of methods for temperature compensation but does not mention wireless transmission.

U.S. Pat. No. 5,987,980 describes a tire valve assembly using a SAW pressure transducer in conjunction with a sealed cavity. This patent does disclose wireless transmission. The assembly includes a power supply and thus this also distinguishes it from the preferred system of this invention. It is not a SAW system and thus the antenna for interrogating the device in this design must be within one meter, which is considerably closer than needed for the preferred device of this invention.

U.S. Pat. No. 5,698,786 relates to the sensors and is primarily concerned with the design of electronic circuits in an interrogator. U.S. Pat. No. 5,700,952 also describes circuitry for use in the interrogator to be used with SAW devices. In neither of these patents is the concept of using a SAW device in a wireless tire pressure monitoring system described. These patents also do not describe including an identification code with the temperature and/or pressure measurements in the sensors and devices.

U.S. Pat. No. 5,804,729 describes circuitry for use with an interrogator in order to obtain more precise measurements of the changes in the delay caused by the physical or chemical property being measured by the SAW device. Similar comments apply to U.S. Pat. No. 5,831,167. Other related prior art includes U.S. Pat. No. 4,895,017.

Other patents disclose the placement of an electronic device in the sidewall or opposite the tread of a tire but they do not disclose either an accelerometer or a surface acoustic wave device. In most cases, the disclosed system has a battery and electronic circuits.

One particular method of measuring pressure that is particularly applicable to this invention is disclosed in V.V. Varadan, Y.R. Roh and V.K. Varadan "Local/Global SAW Sensors for Turbulence", IEEE 1989 Ultrasonics Symposium p. 591-594 makes use of a polyvinylidene fluoride (PVDF) piezoelectric film to measure pressure. Mention is made in this article that other piezoelectric materials can also be used. Experimental results are given where the height of a column of oil is measured based on the pressure measured by the piezoelectric film used as a SAW device. In particular, the speed of the surface acoustic wave is determined by the pressure exerted by the oil on the SAW device. For the purposes of the instant invention, air pressure can also be measured in a similar manner by first placing a thin layer of a rubber material onto the surface of the SAW device which serves as a coupling agent from the air pressure to the SAW surface. In this manner, the absolute pressure of a tire, for example, can be measured without the need for a diaphragm and reference pressure greatly simplifying the pressure measurement. Other examples of the use of PVDF film as a pressure transducer can be found in U.S. Pat. Nos. 4,577,510 and 5,341,687, although they are not used as SAW devices.

The following U.S. patents provide relevant information to this invention: 4,361,026, 4,620,191, 4,7033,27, 4,724,443, 4,725,841, 4,734,698, 5,691,698, 5,841,214, 6,060,815, 6,107,910, 6,114,971, 6,144,332.

Objects of the Invention

It is an object of the invention to provide new and improved sensors for a vehicle which transmit information about a state measured or detected by the sensor wirelessly.

It is another object of the invention to incorporate surface acoustic wave technology into sensors on a vehicle.

It is another object of the invention to provide new and improved sensors for measuring the pressure, temperature and/or acceleration of tires.

It is yet another object of the invention to provide new and improved weight or load measuring sensors, switches, temperature sensors, acceleration sensors, angular position sensors, angular rate sensors, angular acceleration sensors, proximity sensors, rollover sensors, occupant presence and position sensors, strain sensors and humidity sensors which utilize wireless data transmission, wireless power transmission, and/or surface acoustic wave technology.

It is still another object of the present invention to provide new and improved sensors for detecting the presence of fluids or gases which utilize wireless data transmission, wireless power transmission, and/or surface acoustic wave technology.

Yet another object of the present invention to provide new and improved sensors for detecting the condition or friction of a road surface which utilize wireless data transmission, wireless power transmission, and/or surface acoustic wave technology.

Still another object of the present invention to provide new and improved sensors for detecting chemicals which utilize wireless data transmission, wireless power transmission, and/or surface acoustic wave technology.

It is another object of the invention to utilize any of the foregoing sensors for a vehicular component control system in which a component, system or subsystem in the vehicle is controlled based on the information provided by the sensor.

A more general object of the invention is to provide new and improved sensors which obtain and provide information about the vehicle, about individual components, systems, vehicle occupants, subsystems, or about the roadway, ambient atmosphere, travel conditions and external objects.

In order to achieve one or more of the objects mentioned above, the wireless sensing and communication system in accordance with the invention includes sensors that are located on the vehicle or in the vicinity of the vehicle and which provide information which is transmitted to one or more interrogators in the vehicle by wireless radio frequency means, using wireless radio frequency transmission technology. In some cases, the power to operate a particular sensor is supplied by the interrogator while in other cases, the sensor is independently connected to either a battery, generator, vehicle power source or some source of power external to the vehicle.

The sensors for a system installed in a vehicle would likely include tire pressure, temperature and acceleration monitoring sensors, weight or load measuring sensors, switches, temperature, acceleration, angular position, angular rate, angular acceleration, proximity, rollover, occupant presence, humidity, presence of fluids or gases, strain, road condition and friction, chemical sensors and other similar sensors providing information to a vehicle system, vehicle operator or external site. The sensors can provide information about the vehicle and its interior or exterior environment, about individual components, systems, vehicle occupants, subsystems, or about the roadway, ambient atmosphere, travel conditions and external objects.

The system can use one or more interrogators each having one or more antennas that transmit radio frequency energy to the sensors and receive modulated radio frequency signals from the sensors containing sensor and/or identification information. One interrogator can be used for sensing multiple switches or other devices. For example, an interrogator may transmit a chirp form of energy at 905 MHz to 925 MHz to a variety of sensors located within or in the vicinity of the vehicle. These sensors may be of the RFID electronic type or

of the surface acoustic wave (SAW) type. In the electronic type, information can be returned immediately to the interrogator in the form of a modulated RF signal. In the case of SAW devices, the information can be returned after a delay. Naturally, one sensor can respond in both the electronic and SAW delayed modes.

When multiple sensors are interrogated using the same technology, the returned signals from the various sensors can be time, code, space or frequency multiplexed. For example, for the case of the SAW technology, each sensor can be provided with a different delay. Alternately, each sensor can be designed to respond only to a single frequency or several frequencies. The radio frequency can be amplitude or frequency modulated. Space multiplexing can be achieved through the use of two or more antennas and correlating the received signals to isolate signals based on direction.

In general, the sensors will respond with an identification signal followed by or preceded by information relating to the sensed value, state and/or property. In the case of a SAW-based switch, for example, the returned signal may indicate that the switch is either on or off or, in some cases, an intermediate state can be provided signifying that a light should be dimmed, rather than or on or off, for example.

Great economies are achieved by using a single interrogator or even a small number of interrogators to interrogate many types of devices. For example, a single interrogator may monitor tire pressure and temperature, the weight of an occupying item of the seat, the position of the seat and seatback, as well as a variety of switches controlling windows, door locks, seat position, etc. in a vehicle. Such an interrogator may use one or multiple antennas and when multiple antennas are used, may switch between the antennas depending on what is being monitored.

More particularly, the tire monitoring system of this invention actually comprises three separate systems corresponding to three stages of product evolution. Generation 1 is a tire valve cap that provides information as to the pressure within the tire as described below. Generation 2 requires the replacement of the tire valve stem, or the addition of a new stem-like device, with a new valve stem that also measures temperature and pressure within the tire or it may be a device that attaches to the vehicle wheel rim. Generation 3 is a product that is attached to the inside of the tire adjacent the tread and provides a measure of the diameter of the footprint between the tire and the road, the tire pressure and temperature, indications of tire wear and the coefficient of friction between the tire and the road.

Surface acoustic wave technology permits the measurement of many physical and chemical parameters without the requirement of local power or energy. Rather, the energy to run devices is obtained from radio frequency electromagnetic waves. These waves excite an antenna that is coupled to the SAW device. Through various means, the properties of the acoustic waves on the surface of the SAW device are modified as a function of the variable to be measured. The SAW device belongs to the field of microelectromechanical systems (MEMS) and can be produced in high-volume at low cost.

For the generation 1 system, a valve cap contains a SAW material at the end of the valve cap, which may be polymer covered. This device senses the absolute pressure in the valve cap. Upon attaching the valve cap to the valve stem, a depressing member gradually depresses the valve permitting the air pressure inside the tire to communicate with a small volume inside the valve cap. As the valve cap is screwed onto the valve stem, a seal prevents the escape of air to the atmosphere. The SAW device is electrically connected to the valve cap, which is also electrically connected to the valve stem that acts as an antenna for transmitting and receiving radio frequency waves. An interrogator located within 20 feet of the tire periodically transmits radio waves that power the SAW device. The SAW device measures the absolute pressure in the valve cap that is equal to the

pressure in the tire. U.S. Pat. Nos. 5,641,902, 5,819,779 and 4,103,549 illustrate a valve cap pressure sensor where a visual output is provided. Other related prior art includes U.S. Pat. No. 4,545,246.

The generation 2 system permits the measurement of both the tire pressure and tire temperature. In this case, the tire valve stem is removed and replaced with a new tire valve stem that contains a SAW device attached at the bottom of the valve stem. This device actually contains two SAW devices, one for measuring temperature and the second for measuring pressure through a novel technology discussed below. This second generation device therefore permits the measurement of both the pressure and the temperature inside the tire. Alternately, this device can be mounted inside the tire, attached to the rim or attached to another suitable location. An external pressure sensor is mounted in the interrogator to measure the pressure of the atmosphere to compensate for altitude and/or barometric changes.

The generation 3 device contains a pressure and temperature sensor, as in the case of the generation 2 device, but additionally contains one or more accelerometers which measure at least one component of the acceleration of the vehicle tire tread adjacent the device. This acceleration varies in a known manner as the device travels in an approximate circle attached to the wheel. This device is capable of determining when the tread adjacent the device is in contact with road surface. It is also able to measure the coefficient of friction between the tire and the road surface. In this manner, it is capable of measuring the length of time that this tread portion is in contact with the road and thereby provides a measure of the diameter of the tire footprint on the road. A technical discussion of the operating principle of a tire inflation and load detector based on flat area detection follows:

When tires are inflated and not in contact with the ground, the internal pressure is balanced by the circumferential tension in the fibers of the shell. Static equilibrium demands that tension is equal to the radius of curvature multiplied by the difference between the internal and the external gas pressure. Tires support the weight of the automobile by changing the curvature of the part of the shell that touches the ground. The relation mentioned above is still valid. In the part of the shell that gets flattened, the radius of curvature increases while the tension in the tire structure stays the same. Therefore, the difference between the external and internal pressures becomes small to compensate for the growth of the radius. If the shell were perfectly flexible, the tire contact with the ground would develop into a flat spot with an area equal to the load divided by the pressure.

A tire operating at correct values of load and pressure has a precise signature in terms of variation of the radius of curvature in the loaded zone. More flattening indicates under-inflation or overloading, while less flattening indicates over-inflation or under-loading. Note that tire loading has essentially no effect on internal pressure.

From the above, one can conclude that monitoring the curvature of the tire as it rotates can provide a good indication of its operational state. A sensor mounted inside the tire at its largest diameter can accomplish this measurement. Preferably, the sensor would measure mechanical strain. However, a sensor measuring acceleration in any one axis could also serve the purpose.

In the case of the strain measurement, the sensor would indicate a constant strain as it spans the arc over which the tire is not in contact with the ground, and a pattern of increased stretch during the arc of close proximity with the ground. A simple ratio of the times of duration of these two states would provide a good indication of inflation, but more complex algorithms could be employed, where the values and the shape of the period of increased strain are utilized.

In the case of acceleration measurement, the system would utilize the fact that the part of the tire in contact with the ground possesses zero velocity for a finite period of time, while the rest of the tire is accelerating and decelerating in a cyclic fashion. The resulting acceleration profiles in the circumferential axis or the radial axis present a characteristic near-zero portion, the length of which, when related to the rest of the rotation, is a result of the state of tire inflation.

As an indicator of tire health, the measurement of strain on the largest inside diameter of the tire is believed to be superior to the measurement of stress, such as inflation pressure, because, the tire could be deforming, as it ages or otherwise progresses toward failure, without any changes in inflation pressure. Radial strain could also be measured on the inside of the tire sidewall thus indicating the degree of flexure that the tire undergoes.

The accelerometer approach has the advantage of giving a signature from which a harmonic analysis of once-per-revolution disturbances could indicate developing problems such as hernias, flat spots, loss of part of the tread, sticking of foreign bodies to the tread, etc.

As a bonus, both of the above-mentioned sensors give clear once-per-revolution signals for each tire that could be used as inputs for speedometers, odometers, differential slip indicators, tire wear indicators, etc.

Tires can fail for a variety of reasons including low pressure, high temperature, delamination of the tread, excessive flexing of the sidewall, and wear (see, e.g., Summary Root Cause Analysis Bridgestone/Firestone, Inc." http://www.bridgestone-firestone.com/homeimgs/rootcause.htm, Printed March, 2001). Most tire failures can be predicted based on tire pressure alone and the TREAD Act thus addresses the monitoring of tire pressure. However, some failures, such as the Firestone tire failures, can result from substandard materials especially those that are in contact with a steel-reinforcing belt. If the rubber adjacent the steel belt begins to move relative to the belt, then heat will be generated and the temperature of the tire will rise until the tire fails catastrophically. This can happen even in properly inflated tires.

Finally, tires can fail due to excessive vehicle loading and excessive sidewall flexing even if the tire is properly inflated. This can happen if the vehicle is overloaded or if the wrong size tire has been mounted on the vehicle. In most cases, the tire temperature will rise as a result of this additional flexing, however, this is not always the case, and it may even occur too late. Therefore, the device which measures the diameter of the tire footprint on the road is a superior method of measuring excessive loading of the tire.

Generation 1 devices monitor pressure only while generation 2 devices also monitor the temperature and therefore will provide a warning of imminent tire failure more often than through monitoring pressure alone. Generation 3 devices will give an indication that the vehicle is overloaded before either a pressure or temperature monitoring system can respond. The generation 3 system can also be augmented to measure the vibration signature of the tire and thereby detect when a tire has worn to the point that the steel belt is contacting the road. In this manner, the generation 3 system also provides an indication of a worn out tire and, as will be discussed below, an indication of the road coefficient of friction.

Each of these devices communicates to an interrogator with pressure, temperature, and acceleration as appropriate. In none of these generational devices is a battery mounted within the vehicle tire required, although in some cases a generator can be used. In most cases, the SAW devices will optionally provide an identification number corresponding to the device to permit the interrogator to separate one tire from another.

Key advantages of the tire monitoring system disclosed herein over most of the currently known prior art are:

- very small size and insignificant weight eliminating the need for wheel counterbalance,
- cost competitive for tire monitoring only, significant cost advantage when systems are combined,
- exceeds customers' price targets,
- high update rate,
- self-diagnostic,
- automatic wheel identification,
- no batteries required – powerless,
- no wires required – wireless.

SAW devices have been used for sensing many parameters including devices for chemical sensing and materials characterization in both the gas and liquid phase. They also are used for measuring pressure, strain, temperature, acceleration, angular rate and other physical states of the environment.

The monitoring of temperature and or pressure of a tire can take place infrequently. It is adequate to check the pressure and temperature of vehicle tires once every ten seconds to once per minute. To utilize the centralized interrogator of this invention, the tire monitoring system would preferably use SAW technology and the device could be located in the valve stem, wheel, tire tread, or other appropriate location with access to the internal tire pressure of the tires. The preferred system is based on a SAW technology discussed above.

At periodic intervals, such as once every minute, the interrogator sends a radio frequency signal at a frequency such as 905 MHz to which the tire monitor sensors have been sensitized. When receiving this signal, the tire monitor sensors (of which there are five in a typical configuration) respond with a signal providing an optional identification number, temperature and pressure data. In one implementation, the interrogator would use multiple, typically two or four, antennas which are spaced apart. By comparing the returned signals from the tires to the antennas, the location of each of the senders can be approximately determined. That is, the antennas can be so located that each tire is a different distance from each antenna and by comparing the signals sensed by the antennas, the location of each tire can be determined and associated with the returned information. If at least three antennas are used, then returns from adjacent vehicles can be eliminated.

An identification number can accompany each transmission from each tire sensor and can also be used to validate that the transmitting sensor is in fact located on the subject vehicle. In traffic situations, it is possible to obtain a signal from the tire of an adjacent vehicle. This would immediately show up as a return from more than five vehicle tires and the system would recognize that a fault had occurred. The sixth return can be easily eliminated, however, since it could contain an identification number that is different from those that have heretofore been returned frequently to the vehicle system or based on a comparison of the signals sensed by the different antennas. Thus, when the vehicle tire is changed or tires are rotated, the system will validate a particular return signal as originating from the tire-monitoring sensor located on the subject vehicle.

This same concept is also applicable for other vehicle-mounted sensors. This permits a plug and play scenario whereby sensors can be added to, changed, or removed from a vehicle and the interrogation system will automatically adjust. The system will know the type of sensor based on the identification number or its location on the vehicle. For example, a tire monitor could have a different code in the identification number from a switch or weight-monitoring device. This also permits new kinds of sensors to be retroactively installed on a vehicle. If a totally new type of the sensor is mounted to the vehicle, the system software would have to be updated to recognize and know what to do with the information from the new sensor type. By this method, the

configuration and quantity of sensing systems on a vehicle can be easily changed and the system interrogating these sensors need only be updated with software upgrades which could occur automatically over the Internet.

The preferred tire monitoring sensors for use with this invention use the surface acoustic wave (SAW) technology. A radio frequency interrogating signal is sent to all of the tire gages simultaneously and the received signal at each tire gage is sensed using an antenna. The antenna is connected to the IDT transducer that converts the electrical wave to an acoustic wave that travels on the surface of a material such as lithium niobate, or other piezoelectric material such as zinc oxide, Langasite or the polymer polyvinylidene fluoride (PVDF). During its travel on the surface of the piezoelectric material, either the time delay, resonant frequency, amplitude, or phase of the signal is modified based on the temperature and/or pressure in the tire. This modified wave is sensed by one or more IDT transducers and converted back to a radio frequency wave that is used to excite an antenna for re-broadcasting the wave back to interrogator. The interrogator receives the wave at a time delay after the original transmission that is determined by the geometry of the SAW transducer and decodes this signal to determine the temperature and/or pressure in the subject tire. By using slightly different geometries for each of the tire monitors, slightly different delays can be achieved and randomized so that the probability of two sensors having the same delay is small. The interrogator transfers the decoded information to a central processor that then determines whether the temperature and/or pressure of each of the tires exceed specifications. If so, a warning light can be displayed informing the vehicle driver of the condition. In some cases, this random delay is all that is required to separate the five tire signals and to identify which tires are on the vehicle and thus ignore responses from adjacent vehicles.

With an accelerometer mounted in the tire, as is the case for the generation 3 system, information is present to diagnose other tire problems. For example, when the steel belt wears through the rubber tread, it will make a distinctive noise and create a distinctive vibration when it contacts the pavement. This can be sensed by the SAW accelerometer. The interpretation of various such signals can be done using neural network technology. Similar systems are described more detail in U.S. Pat. No. 5,829,782.

As the tread begins to separate from the tire as in the Bridgestone cases, a distinctive vibration is created which can also be sensed by a tire-mounted accelerometer. As the tire rotates, stresses are created in the rubber tread surface between the center of the footprint and the edges. If the coefficient of friction on the pavement is low, these stresses can cause the shape of the footprint to change. The generation 3 system, which measures the circumferential length of the footprint, can therefore also used to measure the friction coefficient between the tire and the pavement.

Similarly, the same or a different interrogator can be used to monitor various components of the vehicle's safety system including occupant position sensors, vehicle acceleration sensors, vehicle angular position, velocity and acceleration sensors, related to both frontal, side or rear impacts as well as rollover conditions. The interrogator could also be used in conjunction with other detection devices such as weight sensors, temperature sensors, accelerometers which are associated with various systems in the vehicle to enable such systems to be controlled or affected based on the measured state.

Some specific examples of the use of interrogators and responsive devices will now be described.

The antennas used for interrogating the vehicle tire pressure transducers will be located outside of the vehicle passenger compartment. For many other transducers to be sensed the antennas must be located at various positions within passenger compartment. This invention contemplates, therefore, a series of different

antenna systems, which can be electronically switched by the interrogator circuitry. Alternately, in some cases, all of the antennas can be left connected and total transmitted power increased.

There are several applications for weight or load measuring devices in a vehicle including the vehicle suspension system and seat weight sensors for use with automobile safety systems. As reported in U.S. Pat. Nos. 4,096,740, 4,623,813, 5,585,571, 5,663,531, 5,821,425 and 5,910,647 and International Publication No. WO 00/65320(A1), SAW devices are appropriate candidates for such weight measurement systems. In this case, the surface acoustic way on the lithium niobate, or other piezoelectric material, is modified in delay time, resonant frequency, amplitude and/or phase based on strain of the member upon which the SAW device is mounted. For example, the conventional bolt that is typically used to connect the passenger seat to the seat adjustment slide mechanism can be replaced with a stud which is threaded on both ends. A SAW strain device is mounted to the center unthreaded section of the stud and the stud is attached to both the seat and the slide mechanism using appropriate threaded nuts. Based on the particular geometry of the SAW device used, the stud can result in as little as a 3 mm upward displacement of the seat compared to a normal bolt mounting system. No wires are required to attach the SAW device to the stud. The interrogator transmits a radio frequency pulse at, for example, 925 MHz that excites antenna on the SAW strain measuring system. After a delay caused by the time required for the wave to travel the length of the SAW device, a modified wave is re-transmitted to the interrogator providing an indication of the strain of the stud with the weight of an object occupying the seat corresponding to the strain. For a seat that is normally bolted to the slide mechanism with four bolts, at least four SAW strain sensors would be used. Naturally, since the individual SAW devices are very small, multiple devices can be placed on a stud to provide multiple redundant measurements and/or to permit the stud to be arbitrarily located with at least one SAW device always within direct view of the interrogator antenna. In some cases, the bolt or stud will be made on non-conductive material to limit the blockage of the RF signal. In other cases, it will be insulated from the slide (mechanism) and used as an antenna.

If two longitudinally spaced apart antennas are used to receive the SAW transmissions from the seat weight sensors, one antenna in front of the seat and the other behind the seat, then the position of the seat can be determined eliminating the need for current seat position sensors. A similar system can be used for other seat and seatback position measurements.

For strain gage weight sensing, the frequency of interrogation would be considerably higher than that of the tire monitor, for example. However, if the seat is unoccupied then the frequency of interrogation can be substantially reduced. For an occupied seat, information as to the identity and/or category and position of an occupying item of the seat can be obtained through the multiple weight sensors described. For this reason, and due to the fact that during the pre-crash event the position of an occupying item of the seat may be changing rapidly, interrogations as frequently as once every 10 milliseconds can be desirable. This would also enable a distribution of the weight being applied to the seat to be obtained which provides an estimation of the position of the object occupying the seat. Using pattern recognition technology, e.g., a trained neural network, sensor fusion, fuzzy logic, etc., the identification of the object can be ascertained based on the determined weight and/or determined weight distribution.

There are many other methods by which SAW devices can be used to determine the weight and/or weight distribution of an occupying item other than the method described above and all such uses of SAW strain sensors for determining the weight and weight distribution of an occupant are contemplated. For example, SAW devices with appropriate straps can be used to measure the deflection of the seat cushion top or bottom

caused by an occupying item, or if placed on the seat belts, the load on the belts can determined wirelessly and powerlessly. Geometries similar to those disclosed in U.S. Pat. No. 6,242,701 using SAW strain-measuring devices can also be constructed, e.g., any of the multiple strain gage geometries shown therein.

Although the preferred method for using the invention is to interrogate each of the SAW devices using wireless means, in some cases it may be desirable to supply power to and/or obtain information from one or more of the devices using wires. As such, the wires would be an optional feature.

Some vehicle models provide load leveling and ride control functions which depend on the magnitude and distribution of load carried by the vehicle suspension. Frequently, wire strain gage technology is used for these functions. That is, the wire strain gages are used to sense the load and/or load distribution of the vehicle on the vehicle suspension system. Such strain gages can be advantageously replaced with strain gages based on SAW technology with the significant advantages in terms of cost, wireless monitoring, dynamic range, and signal level. In addition, SAW strain gage systems can be significantly more accurate than wire strain gage systems.

A strain detector in accordance with this invention can convert mechanical strain to variations in electrical signal frequency with a large dynamic range and high accuracy even for very small displacements. The frequency variation is produced through use of a surface acoustic wave delay line as the frequency control element of an oscillator. A surface acoustic wave delay line comprises a transducer deposited on a piezoelectric material such as quartz or lithium niobate which is disposed so as to be deformed by strain in the member which is to be monitored. Deformation of the piezoelectric substrate changes the frequency control characteristics of the surface acoustic wave delay line, thereby changing the frequency of the oscillator. Consequently, the oscillator frequency change is a measure of the strain in the member being monitored and thus the weight applied to the seat. A SAW strain transducer is capable of a degree of accuracy substantially greater than that of a conventional resistive strain gage.

Other applications of weight measuring systems for an automobile include measuring the weight of the fuel tank or other containers of fluid to determine quantity of fluid contained therein.

One problem with SAW devices is that if they are designed to operate at the GHz frequency, the feature sizes become exceeding small and the devices are difficult to manufacture. On the other hand, if the frequencies are considerably lower, for example, in the tens of megahertz range, then the antenna sizes become excessive. It is also more difficult to obtain antenna gain at the lower frequencies. This is also related to antenna size. One method of solving this problem is to transmit an interrogation signal in the many GHz range which is modulated at the hundred MHz range. At the SAW transducer, the transducer is tuned to the modulated frequency. Using a nonlinear device such as a Shocky diode, the modified signal can be mixed with the incoming high frequency signal and re-transmitted through the same antenna. For this case, the interrogator could continuously broadcast the carrier frequency.

In addition to measuring the weight of an occupying item on a seat, the location of the seat and setback can also be determined by the interrogator. Since the SAW devices inherently create a delayed return signal, either that delay must be very accurately known or an alternate approach is required. One such alternate approach is to use the heterodyne principal described above to cause the antenna to return a signal of a different frequency. By comparing the phases of the sending and received signal, the distance to the device can be determined. Also, as discussed above, multiple antennas can be used for seat position and seatback position sensing.

With respect to switches, devices based on RFID technology can be used as switches in a vehicle as described in U.S. Pat. Nos. 6,078,252 and 6,144,288, and U.S. provisional patent application Ser. No. 60/231,378. There are many ways that it can be accomplished. A switch can be used to connect an antenna to either an RFID electronic device or to an RFID SAW device. This of course requires contacts to the closed by the switch activation. An alternate approach is to use pressure from an occupant's finger, for example, to alter the properties of the acoustic wave on the SAW material much as in a SAW touch screen. These properties that can be modified include the amplitude of the acoustic wave, and its phase, or the time delay or an external impedance connected to one of the SAW reflectors as disclosed in U.S. Pat. No. 6,084,503. In this implementation, the SAW transducer can contain two sections, one which is modified by the occupant and the other which serves as a reference. A combined signal is sent to the interrogator that decodes the signal to determine that the switch has been activated. By any of these technologies, switches can be arbitrarily placed within the interior of an automobile, for example, without the need for wires. (The wires would be an optional feature.) Since wires and connectors are the clause of most warranty repairs in an automobile, not only is the cost of switches substantially reduced but also the reliability of the vehicle electrical system is substantially improved.

The interrogation of switches can take place with moderate frequency such as once every 100 milliseconds. Either through the use of different frequencies or different delays, a large number of switches can be either time, code, space or frequency multiplexed to permit separation of the signals obtained by the interrogator.

Another approach is to attach a variable impedance device across one of the reflectors on the SAW device. The impedance can therefore used to determine the relative reflection from the reflector compared to other reflectors on the SAW device. In this way, the magnitude as well as the presence of a force exerted by an occupant's finger, for example, can be used to provide a rate sensitivity to the desired function. In an alternate design, shown in U.S. Pat. No. 6,144,288, the switch is used to connect the antenna to the SAW device. Of course, in this case the interrogator will not get a return from the SAW switch unless it is depressed.

Temperature measurement is another field in which SAW technology can be applied and the invention encompasses several embodiments of SAW temperature sensors.

U.S. Pat. No. 4,249,418 is one of many examples of prior art SAW temperature sensors. Temperature sensors are commonly used within vehicles and many more applications might exist if a low cost wireless temperature sensor is available, i.e., the invention. The SAW technology can be used for such temperature sensing tasks. These tasks include measuring the vehicle coolant temperature, air temperature within passenger compartment at multiple locations, seat temperature for use in conjunction with seat warming and cooling systems, outside temperatures and perhaps tire surface temperatures to provide early warning to operators of road freezing conditions. One example, is to provide air temperature sensors in the passenger compartment in the vicinity of ultrasonic transducers used in occupant sensing systems as described in U.S. Pat No. 5,943,295, since the speed of sound in the air varies by approximately 20% from -40 °C to 85 °C. The subject matter of this patent is included in the invention to form a part thereof. Current ultrasonic occupant sensor systems do not measure or compensate for this change in the speed of sound with the effect of significantly reducing the accuracy of the systems at the temperature extremes. Through the judicious placement of SAW temperature sensors in the vehicle, the passenger compartment air temperature can be accurately estimated and the

information provided wirelessly to the ultrasonic occupant sensor system thereby permitting corrections to be made for the change in speed of sound.

Acceleration sensing is another field in which SAW technology can be applied and the invention encompasses several embodiments of SAW accelerometers.

U.S. Pat. Nos. 4,199,990, 4,306,456 and 4,549,436 are examples of prior art SAW accelerometers. Most airbag crash sensors for determining whether the vehicle is experiencing a frontal or side impact currently use micromachined accelerometers. These accelerometers are usually based on the deflection of a mass which is sensed using either capacitive or piezoresistive technologies. SAW technology has heretofore not been used as a vehicle accelerometer or for vehicle crash sensing. Due to the importance of this function, at least one interrogator could be dedicated to this critical function. Acceleration signals from the crash sensors should be reported at least preferably every 100 microseconds. In this case, the dedicated interrogator would send an interrogation pulse to all crash sensor accelerometers every 100 microseconds and receive staggered acceleration responses from each of the SAW accelerometers wirelessly. This technology permits the placement of multiple low-cost accelerometers at ideal locations for crash sensing including inside the vehicle side doors, in the passenger compartment and in the frontal crush zone. Additionally crash sensors can now be located in the rear of the vehicle in the crush zone to sense rear impacts. Since the acceleration data is transmitted wirelessly, concern about the detachment or cutting of wires from the sensors disappears. One of the main concerns, for example, of placing crash sensors in the vehicle doors where they most appropriately can sense vehicle side impacts, is the fear that an impact into the A-pillar of the automobile would sever the wires from the door-mounted crash sensor before the crash was sensed. This problem disappears with the current wireless technology of this invention.

Although the sensitivity of measurement is considerably greater than that obtained with conventional piezoelectric accelerometers, the frequency deviation remains low in absolute value. Accordingly, the frequency drift of thermal origin has to be made as low as possible by selecting a suitable cut of the piezoelectric material. The resulting accuracy is impressive as presented in U.S. Pat. No. 4,549,436 which discloses an angular accelerometer with a dynamic a range of 1 million, temperature coefficient of 0.005%/deg F, an accuracy of 1 microradian/sec^2, a power consumption of 1 milliwatt, a drift of 0.01% per year, a volume of 1 cc/axis and a frequency response of 0 to 1000 Hz. The subject matter of this patent is hereby included in the invention to constitute a part of the invention. A similar design can be used for acceleration sensing.

In a similar manner as the polymer coated SAW device is used to measure pressure, a similar device wherein a seismic mass is attached to a SAW device through a polymer interface can be made to sense acceleration. This geometry has a particular advantage for sensing accelerations below 1 G, which has proved to be very difficult in conventional micromachined accelerometers due to their inability to both measure low accelerations and withstand shocks.

Gyroscopes are another field in which SAW technology can be applied and the invention encompasses several embodiments of SAW gyroscopes.

The SAW technology is particularly applicable for gyroscopes as described in International Publication No. WO 00/79217. The output of such gyroscopes can be determined with an interrogator that is also used for the crash sensor accelerometers, or a dedicated interrogator can be used. Gyroscopes having an accuracy of approximately 1 degree per second have many applications in a vehicle including skid control and other

dynamic stability functions. Additionally, gyroscopes of similar accuracy can be used to sense impending vehicle rollover situations in time to take corrective action.

SAW gyroscopes of the type described in WO 00/79217 have the capability of achieving accuracies approaching 3 degrees per hour. This high accuracy permits use of such gyroscopes in an inertial measuring unit (IMU) that can be used with accurate vehicle navigation systems and autonomous vehicle control based on differential GPS corrections. Such a system is described in U.S. patent application Ser. No. 09/177,041. Such navigation systems depend on the availability of four or more GPS satellites and an accurate differential correction signal such as provided by the OmniStar Corporation or NASA. The availability of these signals degrades in urban canyon environments, tunnels, and on highways when the vehicle is in the vicinity of large trucks. For this application, an IMU system should be able to accurately control the vehicle for at least 15 seconds and preferably for up to five minutes. An IMU based on SAW technology or the technology of U.S. Pat. No. 4,549,436 discussed above is the best-known device capable of providing sufficient accuracies for this application at a reasonable cost. Other accurate gyroscope technologies such as fiber optic systems are more accurate but can cost many thousands of dollars. In contrast, in high volume production, an IMU of the required accuracy based on SAW technology should cost less than $100.

Once an IMU of the accuracy described above is available in the vehicle, this same device can be used to provide significant improvements to vehicle stability control and rollover prediction systems.

Keyless entry systems are another field in which SAW technology can be applied and the invention encompasses several embodiments of access control systems using SAW devices.

A common use of SAW technology is for access control to buildings. RFID technology using electronics is also applicable for this purpose; however, the range of electronic RFID technology is usually limited to one meter or less. In contrast, the SAW technology can permit sensing up to about 30 meters. As a keyless entry system, an automobile can be configured such that the doors unlock as the holder of a card containing the SAW ID system approaches the vehicle and similarly, the vehicle doors can be automatically locked when occupant with the card travels beyond a certain distance from the vehicle. When the occupant enters the vehicle, the doors can again automatically lock either through logic or through a current system wherein doors automatically lock when the vehicle is placed in gear. An occupant with such a card would also not need to have an ignition key. The vehicle would recognize that the SAW based card was inside vehicle and then permit the vehicle to be started by depressing a button, for example, without the need for an ignition key.

Occupant presence and position sensing is another field in which SAW technology can be applied and the invention encompasses several embodiments of SAW occupant presence and/or position sensors.

Many sensing systems are available for the use to identify and locate occupants or other objects in a passenger compartment of the vehicle. Such sensors include ultrasonic sensors, chemical sensors (e.g. carbon dioxide), cameras, radar systems, heat sensors, capacitance, magnetic or other field change sensors, etc. Most of these sensors require power to operate and return information to a central processor for analysis. An ultrasonic sensor, for example, may be mounted in or near the headliner of the vehicle and periodically it transmits a few ultrasonic waves and receives reflections of these waves from occupying items of the passenger seat. Current systems on the market are controlled by electronics in a dedicated ECU.

An alternate method as taught in this invention is to use an interrogator to send a signal to the headliner-mounted ultrasonic sensor causing that sensor to transmit and receive ultrasonic waves. The sensor in this case would perform mathematical operations on the received waves and create a vector of data containing

perhaps twenty to forty values and transmit that vector wirelessly to the interrogator. By means of this system, the ultrasonic sensor need only be connected to the vehicle power system and the information could be transferred to and from the sensor wirelessly. Such a system significantly reduces the wiring complexity especially when there may be multiple such sensors distributed in the passenger compartment. Now, only a power wire needs to be attached to the sensor and there does not need to be any direct connection between the sensor and the control module. Naturally, the same philosophy would apply to radar-based sensors, electromagnetic sensors of all kinds including cameras, capacitive or other electromagnetic field change sensitive sensors etc. In some cases, the sensor itself can operate on power supplied by the interrogator through radio frequency transmission. In this case, even the connection to the power line can be omitted. This principle can be extended to the large number of sensors and actuators that are currently in the vehicle where the only wires that are needed are those to supply power to the sensors and actuators and the information is supplied wirelessly.

Such wireless powerless sensors can also be use, for example, as close proximity sensors based on measurement of thermal radiation from an occupant. Such sensors can be mounted on any of the surfaces in the passenger compartment, including the seats, which are likely to receive such radiation.

A significant number of people are suffocated each year in automobiles due to excessive heat, carbon dioxide, carbon monoxide, or other dangerous fumes. The SAW sensor technology is particularly applicable to solving these kinds of problems. The temperature measurement capabilities of SAW transducers have been discussed above. If the surface of a SAW device is covered with a material which captures carbon dioxide, for example, such that the mass, elastic constants or other property of surface coating changes, the characteristics of the surface acoustic waves can be modified as described in detail in U.S. Pat. No. 4,637,987 and elsewhere. Once again, an interrogator can sense the condition of these chemical-sensing sensors without the need to supply power and connect the sensors with either wireless communication or through the power wires. If a concentration of carbon monoxide is sensed, for example, an alarm can be sounded, the windows opened, and/or the engine extinguished. Similarly, if the temperature within the passenger compartment exceeds a certain level, the windows can be automatically opened a little to permit an exchange of air reducing the inside temperature and thereby perhaps saving the life of an infant or pet left in the vehicle unattended.

In a similar manner, the coating of the surface wave device can contain a chemical which is responsive to the presence of alcohol. In this case, the vehicle can be prevented from operating when the concentration of alcohol vapors in the vehicle exceeds some determined limit.

Each year a number of children and animals are killed when they are locked into a vehicle trunk. Since children and animals emit significant amounts of carbon dioxide, a carbon dioxide sensor connected to the vehicle system wirelessly and powerlessly provides an economic way of detecting the presence of a life form in the trunk. If a life form is detected, then a control system can release a trunk lock thereby opening the trunk. Alarms can also be sounded or activated when a life form is detected in the trunk.

Although they will not be discussed in detail, SAW sensors operating in the wireless mode can also be used to sense for ice on the windshield or other exterior surfaces of the vehicle, condensation on the inside of the windshield or other interior surfaces, rain sensing, heat load sensing and many other automotive sensing functions. They can also be used to sense outside environmental properties and states including temperature, humidity, etc.

SAW sensors can be economically used to measure the temperature and humidity at numerous places both inside and outside of a vehicle. When used to measure humidity inside the vehicle, a source of water vapor can be activated to increase the humanity when desirable and the air conditioning system can be activated to reduce the humidity when necessary. Temperature and humidity measurements outside of the vehicle can be an indication of potential road icing problems. Such information can be used to provide early warning to a driver of potentially dangerous conditions.

Road condition sensing is another field in which SAW technology can be applied and the invention encompasses several embodiments of SAW road condition sensors.

The temperature and moisture content of the surface of a roadway are critical parameters in determining the icing state of the roadway. Attempts have been made to measure the coefficient of friction between a tire and the roadway by placing strain gages in the tire tread. Naturally, such strain gages are ideal for the application of SAW technology especially since they can be interrogated wirelessly from a distance and they require no power for operation. As discussed above, SAW accelerometers can also perform this function. The measurement of the friction coefficient, however, is not predictive and the vehicle operator is only able to ascertain the condition after the fact. SAW based transducers have the capability of being interrogated as much as 100 feet from the interrogator. Therefore, the judicious placement of low-cost powerless SAW temperature and humidity sensors in or on the roadway at critical positions can provide an advance warning to vehicle operators that road is slippery ahead. Such devices are very inexpensive and therefore could be placed at frequent intervals along a highway.

Some lateral control of the vehicle can also be obtained from SAW transducers or electronic RFID tags placed down the center of the lane, either above the vehicles or in the roadway, for example. A vehicle having two receiving antennas approaching such devices, through triangulation, is able to determine the lateral location of the vehicle relative to these SAW devices. If the vehicle also has an accurate map of the roadway, the identification number associated with each such device can be used to obtain highly accurate longitudinal position determinations. Ultimately, the SAW devices can be placed on structures beside the road and perhaps on every mile or tenth of a mile marker. If three antennas are used, as discussed herein, the distances to the SAW device can be determined.

Electronic RFID tags are also suitable for lateral and longitudinal positioning purposes, however, the range available for electronic RFID systems is considerably less than that of SAW based systems. On the other hand, as taught in co-pending U.S. provisional patent application Ser. No. 60/231,378, the time of flight of the RFID system can be used to determine the distance from the vehicle to the RFID tag. Because of the inherent delay in the SAW devices and its variation with temperature, accurate distance measurement is probably not practical based on time of flight but somewhat less accurate distance measurements based on relative time of arrival can be made. Even if the exact delay imposed by the SAW device was accurately known at one temperature, such devices are usually reasonably sensitive to changes in temperature, hence they make good temperature sensors, and thus the accuracy of the delay in the SAW device is more difficult to maintain. An interesting variation of an electronic RFID that is particularly applicable to this and other applications of this invention is disclosed in A. Pohl, L. Reindl, "New passive sensors", Proc. 16th IEEE Instrumentation and Measurement Technology Conf., IMTC/99, 1999, pp. 1251-1255.

Many SAW devices are based on lithium niobate or similar strong piezoelectric materials. Such materials have high thermal expansion coefficients. An alternate material is quartz that has a very low thermal

expansion coefficient. However, its piezoelectric properties are inferior to lithium niobate. One solution to this problem is to use lithium niobate as the coupling system between the antenna and the material upon which the surface acoustic wave travels. In this matter, the advantages of a low thermal expansion coefficient material can be obtained while using the lithium niobate for its strong piezoelectric properties. Other useful materials such as Langasite have properties that are intermediate between lithium niobate and quartz. Note that it is also possible to use combinations of materials to achieve particular objectives with property measurement since different materials respond differently to different sensed properties or environments.

The use of SAW tags as an accurate precise positioning system as described above would be applicable for accurate vehicle location, as discussed in U.S. patent application Ser. No. 09/177,041, for lanes in tunnels, for example, or other cases where loss of satellite lock is common.

The various technologies discussed above can be used in combination. The electronic RFID tag can be incorporated into a SAW tag providing a single device that provides both an instant reflection of the radio frequency waves as well as a re-transmission at a later time. This marriage of the two technologies permits the strengths of each technology to be exploited in the same device. For most of the applications described herein, the cost of mounting such a tag in a vehicle or on the roadway far exceeds the cost of the tag itself. Therefore, combining the two technologies does not significantly affect the cost of implementing tags onto vehicles or roadways or side structures. Nevertheless, the RFID technology and SAW technology can be used independently of one another.

Another field in which SAW technology can be applied is for "ultrasound-on-a-surface" type of devices.

U.S. Pat. No. 5,629,681 describes many uses of ultrasound in a tube. Many of the applications are also candidates for ultrasound-on-a-surface devices. In this case, a micromachined SAW device will in general be replaced by a much larger structure.

Touch screens based on surface acoustic waves are well known in the art. The use of this technology for a touch pad for use with a heads-up display is disclosed in the U.S. patent application Ser. No. 09/645,709. The use of surface acoustic waves in either one or two dimensional applications has many other possible uses such as for pinch protection on window and door closing systems, crush sensing crash sensors, occupant presence detector and butt print measurement systems, generalized switches such as on the circumference or center of the steering wheel, etc. Since these devices typically require significantly more power than the micromachined SAW devices discussed above, most of these applications will require a power connection. On the other hand, the output of these devices can go through a SAW micromachined device or, in some other manner, be attached to an antenna and interrogated using a remote interrogator thus eliminating the need for a direct wire communication link.

One example would be to place a surface acoustic wave device on the circumference of the steering wheel. Upon depressing a section of this device, the SAW wave would be attenuated. The interrogator would notify the acoustic wave device at one end of the device to launch an acoustic wave and then monitor output from the antenna. Depending on the phase, time delay, and/or amplitude of the output wave, the interrogator would know where the operator had depressed the steering wheel SAW switch and therefore know the function desired by the operator.

Piezoelectric generators are another field in which SAW technology can be applied and the invention encompasses several embodiments of SAW piezoelectric generators.

An alternate approach for some applications, such as tire monitoring, where it is difficult to interrogate the SAW device as the wheel, and thus the antenna, is rotating, the transmitting power can be significantly increased if there is a source of energy inside the tire. Many systems now use a battery but this leads to problems related to having to periodically replace the battery and temperature effects. In some cases, the manufacturers recommend that the batter be replaced as often as every 6 to 12 months. Batteries also sometimes fail to function properly at cold temperatures and have their life reduced when operated at high temperatures. For these reasons, there is a strong belief that a tire monitoring system should obtain its power from some source external of the tire. Similar problems can be expected for other applications.

One novel solution to this problem is to use the flexing of the tire itself to generate electricity. If a thin film of PVDF is attached to the tire inside and adjacent to the tread, then as the tire rotates the film will flex and generate electricity. This energy can then be stored on one or more capacitors and used to power the tire monitoring circuitry. Also, since the amount of energy that is generated depends of the flexure of the tire, this generator can also be used to monitor the health of the tire in a similar manner as the generation 3 accelerometer system described above.

As mentioned above, the transmissions from different SAW devices can be time multiplexed by varying the delay time from device to device, frequency multiplexed by varying the natural frequencies of the SAW devices, code multiplexed by varying the identification code of the SAW devices or space multiplexed by using multiple antennas. Considering the time multiplexing case, varying the length of the SAW device and thus the delay before retransmission can separate different classes of devices. All seat sensors can have one delay which would be different from tire monitors or light switches etc.

Definitions

The term "gage" as used herein interchangeably with the terms "sensor" and "sensing device".

Further, the applicants intend that everything disclosed above can be used in combination on a single vehicle.

Brief Description of the Drawings

The following drawings are illustrative of embodiments of the invention and are not meant to limit the scope of the invention as encompassed by the claims.

FIG. 1A is a partial cutaway view of a tire pressure monitor using an absolute pressure measuring SAW device.

FIG. 1B is a partial cutaway view of a tire pressure monitor using a differential pressure measuring SAW device.

FIG. 2 is a partial cutaway view of an interior SAW tire temperature and pressure monitor mounted onto and below the valve stem.

FIG. 2A is a sectioned view of the SAW tire pressure and temperature monitor of FIG. 2 incorporating an absolute pressure SAW device.

FIG. 2B is a sectioned view of the SAW tire pressure and temperature monitor of FIG. 2 incorporating a differential pressure SAW device.

FIG. 3 is a view of an accelerometer-based tire monitor also incorporating a SAW pressure and temperature monitor and cemented to the interior of the tire opposite the tread.

FIG. 3A is a view of an accelerometer-based tire monitor also incorporating a SAW pressure and temperature monitor and inserted into the tire opposite the tread during manufacture.

FIG. 4 is a detailed view of a polymer on SAW pressure sensor.

FIG. 4A is a view of a SAW temperature and pressure monitor on a single SAW device.

FIG. 4B is a view of an alternate design of a SAW temperature and pressure monitor on a single SAW device.

FIG. 5 is a perspective view of a SAW temperature sensor.

FIG. 5A is a perspective view of a device that can provide two measurements of temperature or one of temperature and another of some other physical or chemical property such as pressure or chemical concentration.

FIG. 5B is a top view of an alternate SAW device capable of determining two physical or chemical properties such as pressure and temperature.

FIGS. 6 and 6A are views of a prior art SAW accelerometer that can be used for the tire monitor assembly of FIG. 3.

FIGS. 7A, 7B, 7C and 7D are views of occupant seat weight sensors using a slot spanning SAW strain gage and other strain concentrating designs.

FIG. 8A is a view of a view of a SAW switch sensor for mounting on or within a surface such as a vehicle armrest.

FIG. 8B is a detailed perspective view of the device of FIG. 8A with the force-transmitting member rendered transparent.

FIG. 8C is a detailed perspective view of an alternate SAW device for use in FIGS. 8A and 8B showing the use of one of two possible switches, one that activates the SAW and the other that suppresses the SAW.

FIG. 9A is a detailed perspective view of a polymer and mass on SAW accelerometer for use in crash sensors, vehicle navigation, etc.

FIG. 9B is a detailed perspective view of a normal mass on SAW accelerometer for use in crash sensors, vehicle navigation, etc.

FIG. 10 is a view of a prior art SAW gyroscope that can be used with this invention.

FIG. 11A, 11B and 11C are a block diagrams of three interrogators that can be used with this invention to interrogate several different devices.

FIG. 12 is a perspective view of a SAW antenna system adapted for mounting underneath a vehicle and for communicating with the four mounted tires.

FIG. 12A is a detail view of an antenna system for use in the system of FIG. 12.

FIG. 13 is a perspective view of a carbon dioxide SAW sensor for mounting in the trunk lid for monitoring the inside of the trunk for detecting trapped children or animals.

FIG. 13A is a detailed view of the SAW carbon dioxide sensor of FIG. 13.

FIG. 14 is an overhead view of a roadway with vehicles and a SAW road temperature and humidity monitoring sensor.

FIG. 14A is a detail drawing of the monitoring sensor of FIG. 14.

FIG. 15 is a perspective view of a SAW system for locating a vehicle on a roadway, and on the earth surface if accurate maps are available. It also illustrates the use of a SAW transponder in the license plate for the location of preceding vehicles and preventing rear end impacts.

FIG. 16 is a partial cutaway view of a section of a fluid reservoir with a SAW fluid pressure and temperature sensor for monitoring oil, water, or other fluid pressure.

FIG. 17 is a perspective view of a vehicle suspension system with SAW load sensors.

FIG. 17A is a cross section detail view of a vehicle spring and shock absorber system with a SAW torque sensor system mounted for measuring the stress in the vehicle spring of the suspension system of FIG. 17.

FIG. 17B is a detail view of a SAW torque sensor and shaft compression sensor arrangement for use with the arrangement of FIG. 17.

FIG. 18 is a cutaway view of a vehicle showing possible mounting locations for vehicle interior temperature, humidity, carbon dioxide, carbon monoxide, alcohol or other chemical or physical property measuring sensors.

FIG. 19A is a perspective view of a SAW tilt sensor using four SAW assemblies for tilt measurement and one for temperature.

FIG. 19B is a top view of a SAW tilt sensor using three SAW assemblies for tilt measurement each one of which can also measure temperature.

FIG. 20 is a perspective exploded view of a SAW crash sensor for sensing frontal, side or rear crashes.

FIG. 21 is a partial cutaway view of a piezoelectric generator and tire monitor using PVDF film.

FIG. 21A is a cutaway view of the PVDF sensor of FIG. 21.

FIG. 22 is a perspective view with portions cutaway of a SAW based vehicle gas gage.

FIG. 22A is a top detailed view of a SAW pressure and temperature monitor for use in the system of FIG. 22.

FIG. 23 is a partial cutaway view of a vehicle drives wearing a seatbelt with SAW force sensors.

FIG. 24 is an alternate arrangement of a SAW tire pressure and temperature monitor installed in the wheel rim facing inside.

Detailed Description of the Preferred Embodiments

Referring now to the drawings wherein the same reference numerals refer to the same or similar elements, a first embodiment of a valve cap 10 including a tire pressure monitoring system in accordance with the invention is shown generally at 10 in FIG. 1A. A tire 1 has a protruding, substantially cylindrical valve stem 2 which is shown in a partial cutaway view in FIG. 1A. The valve stem 2 comprises a sleeve 3 and a tire valve assembly 5. The sleeve 3 of the valve stem 2 is threaded on both its inner surface and its outer surface. The tire valve assembly 5 is arranged in the sleeve 3 and includes threads on an outer surface which are mated with the threads on the inner surface of the sleeve 3. The valve assembly 5 comprises a valve seat 4 and a valve pin 6 arranged in an aperture in the valve seat 4. The valve assembly 5 is shown in the open condition in FIG. 1A whereby air flows through a passage between the valve seat 4 and the valve pin 6..

The valve cap 10 includes a substantially cylindrical body 9 and is attached to the valve stem 2 by means of threads 8 arranged on an inner cylindrical surface of body 9 which are mated with the threads on the outer surface of the sleeve 3. The valve cap 10 comprises a valve pin depressor 14 arranged in connection with the body 9 and a SAW pressure sensor 11. The valve pin depressor 14 engages the valve pin 6 upon attachment of the valve cap 10 to the valve stem 2 and depresses it against its biasing spring, not shown, thereby opening the passage between the valve seat 4 and the valve pin 6 allowing air to pass from the interior of tire 1 into a

reservoir or chamber 12 in the body 9. Chamber 12 contains the SAW pressure sensor 11 as described in more detail below.

Pressure sensor 11 is an absolute pressure-measuring device. It functions based on the principle that the increase in air pressure and thus air density in the chamber 12 increases the mass loading on a SAW device changing the velocity of surface acoustic wave on the piezoelectric material. The pressure sensor 11 is therefore positioned in an exposed position in the chamber 12.

A second embodiment of a valve cap 10' in accordance with the invention is shown in FIG. 1B and comprises a SAW strain sensing device 15 that is mounted onto a flexible membrane 13 attached to the body 9' of the valve cap 10' and in a position in which it is exposed to the air in the chamber 12'. When the pressure changes in chamber 12', the deflection of the membrane 13 changes thereby changing the stress in the SAW device 15.

Strain sensor 15 is thus a differential pressure-measuring device. It functions based on the principle that changes in the flexure of the membrane 13 can be correlated to changes in pressure in the chamber 12' and thus, if an initial pressure and flexure are known, the change in pressure can be determined from the change in flexure.

FIGS. 1A and 1B therefore illustrate two different methods of using a SAW sensor in a valve cap for monitoring the pressure inside a tire. The precise manner in which the SAW sensors 11,15 operate is discussed fully below but briefly, each sensor 11,15 includes an antenna and an interdigital transducer which receives a wave via the antenna from an interrogator which proceeds to travel along a substrate (the membrane in the embodiment of FIG. 1B). The time in which the waves travel across the substrate and return to the interdigital transducer is dependent on the temperature, the mass loading on the substrate (in the embodiment of FIG. 1A) or the flexure of membrane 13 (in the embodiment of FIG. 1B). The antenna transmits a return wave which is receives and the time delay between the transmitted and returned wave is calculated and correlated to the pressure in the chamber 12.

Sensors 11 and 15 are electrically connected to the metal valve cap 10 that is electrically connected to the valve stem 2. The valve stem 2 is electrically isolated from the tire rim and serves as an antenna for transmitting radio frequency electromagnetic signals from the sensors 11 and 15 to a vehicle mounted interrogator, not shown, to be described in detail below. As shown in FIG. 1A, a pressure seal 16 is arranged between an upper rim of the sleeve 3 and an inner shoulder of the body 9 of the valve cap 10 and serves to prevent air from flowing out of the tire 1 to the atmosphere.

The speed of the surface acoustic wave on the piezoelectric substrate changes with temperature in a predictable manner as well as with pressure. For the valve cap implementations, a separate SAW device can attached to the outside of the valve cap and protected with a cover where it is subjected to the same temperature as the SAW sensors 11 or 15 but is not subject to pressure or strain. This requires that each valve cap comprise two SAW devices, one for pressure sensing and another for temperature sensing. Since the valve cap is exposed to ambient temperature, a preferred approach is to have a single device on the vehicle which measures ambient temperature outside of the vehicle passenger compartment. Many vehicles already have such a temperature sensor. For those installations where access to this temperature data is not convenient, a separate SAW temperature sensor can be mounted associated with the interrogator antenna, as illustrated below, or some other convenient place.

Although the valve cap 10 is provided with the pressure seal 16, there is a danger that the valve cap 10 will not be properly assembled onto the valve stem 2 and a small quantity of the air will leak over time. FIG. 2 provides an alternate design where the SAW temperature and pressure measuring devices are incorporated into the valve stem. This embodiment is thus particularly useful in the initial manufacture of a tire.

The valve stem assembly is shown generally at 20 and comprises a brass valve stem 7 which contains a tire valve assembly 5. The valve stem 7 is covered with a coating 21 of a resilient material such as rubber, which has been partially removed in the drawing. A metal conductive ring 22 is electrically attached to the valve stem 7. A rubber extension 23 is also attached to the lower end of the valve stem 7 and contains a SAW pressure and temperature sensor 24. The SAW pressure and temperature sensor 24 can be of at least two designs wherein the SAW sensor is used as an absolute pressure sensor as shown in FIG. 2A or an as a differential sensor based on membrane strain as shown in FIG. 2B.

In FIG. 2A, the SAW sensor 24 comprises a capsule 32 having an interior chamber in communication with the interior of the tire via a passageway 30. A SAW absolute pressure sensor 27 is mounted onto one side of a rigid membrane or separator 31 in the chamber in the capsule 32. Separator 31 divides the interior chamber of the capsule 32 into two compartments 25 and 26, with only compartment 25 being in flow communication with the interior of the tire. The SAW absolute pressure sensor 27 is mounted in compartment 25 which is exposed to the pressure in the tire through passageway 30. A SAW temperature sensor 28 is attached to the other side of the separator 31 and is exposed to the pressure in compartment 26. The pressure in compartment 26 is unaffected by the tire pressure and is determined by the atmospheric pressure when the device was manufactured and the effect of temperature on this pressure. The speed of sound on the SAW temperature sensor 28 is thus affected by temperature but not by pressure in the tire.

The operation of SAW sensors 27 and 28 is discussed elsewhere more fully but briefly, since SAW sensor 27 is affected by the pressure in the tire, the wave which travels along the substrate is affected by this pressure and the time delay between the transmission and reception of a wave can be correlated to the pressure. Similarly, since SAW sensor 28 is affected by the temperature in the tire, the wave which travels along the substrate is affected by this temperature and the time delay between the transmission and reception of a wave can be correlated to the temperature.

FIG. 2B illustrates an alternate configuration of sensor 24 where a flexible membrane 33 is used instead of the rigid separator 31 shown in the embodiment of FIG. 2A, and a SAW device is mounted on flexible member 33. In this embodiment, the SAW temperature sensor 28' is mounted to a different wall of the capsule 32'. A SAW device 29' is thus affected both by the strain in membrane 33 and the absolute pressure in the tire. Normally, the strain effect will be much larger with a properly designed membrane 33.

The operation of SAW sensors 28' and 29' is discussed elsewhere more fully but briefly, since SAW sensor 28' is affected by the temperature in the tire, the wave which travels along the substrate is affected by this temperature and the time delay between the transmission and reception of a wave can be correlated to the temperature. Similarly, since SAW sensor 29' is affected by the pressure in the tire, the wave which travels along the substrate is affected by this pressure and the time delay between the transmission and reception of a wave can be correlated to the pressure.

In both of the embodiments shown in FIG. 2A and FIG. 2B, a separate temperature sensor is illustrated. This has two advantages. First, it permits the separation of the temperature effect from the pressure effect on the SAW device. Second, it permits a measurement of tire temperature to be recorded. Since a normally inflated

tire can experience excessive temperature caused, for example, by an overload condition, it is desirable to have both temperature and pressure measurements of each vehicle tire

The SAW devices 27, 28, 28' and 29' are electrically attached to the valve stem 7 which again serves as an antenna to transmit radio frequency information to an interrogator. This electrical connection can be made by a wired connection; however, the impedance between the SAW devices and the antenna may not be properly matched. An alternate approach as described in Varadan, V.K. et al "Fabrication, characterization and testing of wireless MEMS-IDT based microaccelerometers" Sensors and Actuators A 90 (2001) p. 7-19, 2001 Elsevier Netherlands, is to inductively couple the SAW devices to the brass tube.

Although an implementation into the valve stem and valve cap examples have been illustrated above, an alternate approach is to mount the SAW temperature and pressure monitoring devices elsewhere within the tire. Similarly, although the tire stem in both cases above serves the antenna, in many implementations, it is preferable to have a separately designed antenna mounted within or outside of the vehicle tire. For example, such an antenna can project into the tire from the valve stem or can be separately attached to the tire or tire rim either inside or outside of the tire.

A more advanced embodiment of a tire monitor in accordance with the invention is illustrated generally at 40 in FIGS. 3 and 3A. In addition to temperature and pressure monitoring devices as described in the previous applications, the tire monitor assembly 40 comprises an accelerometer of any of the types to be described below which is configured to measure either or both of the tangential and radial accelerations. Tangential accelerations as used herein mean accelerations tangent to the direction of rotation of the tire and radial accelerations as used herein mean accelerations toward or away from the wheel axis. For either accelerometer case, the acceleration will be zero when the monitor assembly 40 is closest to the road and will be at a maximum when the monitor assembly 40 is at its maximum distance from the road. Both accelerations will increase and decrease at all positions in between.

In FIG. 3, the tire monitor assembly 40 is cemented to the interior of the tire opposite the tread. In FIG. 3A, the tire monitor assembly 40 is inserted into the tire opposite the tread during manufacture.

Superimposed on the acceleration signals will be vibrations introduced into tire from road interactions and due to tread separation. Additionally, the presence of the nail or other object attached to the tire will, in general, excite vibrations that can be sensed by the accelerometers. When the tread is worn to the extent that the wire belts 41 begin impacting the road, additional vibrations will be induced.

Through monitoring the acceleration signals from the tangential or radial accelerometers within the tire monitor assembly 40, delamination, a worn tire condition, imbedded nails, other debris attached to the tire tread, can all be sensed. Additionally, as previously discussed, the length of time that the tire tread is in contact with the road opposite tire monitor 40 can be measured and, through a comparison with the total revolution time, the length of the tire footprint on the road can be determined. This permits the load on the tire to be measured, thus providing an indication of excessive tire loading. As discussed above, a tire can fail due to over loading even when the tire interior temperature and pressure are within acceptable limits. Other tire monitors cannot sense such conditions.

Since the acceleration changes during the rotation of the tire, a simple switch containing an acceleration sensing mass can now be designed that would permit data transmission only during one part of the tire rotation. Such a switch can be designed, for example, such that it shorts out the antenna except when the tire is experiencing zero acceleration at which time it permits the device to transmit data to the interrogator. Such a

system would save on battery power, for example, for powered systems and minimize bandwidth use for passive systems.

In the discussion above, the use of the tire valve stem as an antenna has been discussed. An antenna can also be placed within the tire when the tire sidewalls are not reinforced with steel. In some cases and for some frequencies, it is sometimes possible to use the tire steel bead or steel belts, which in some cases can be coupled to inductively.

Although the discussion above has centered on the use of SAW devices, the configuration of FIG. 3 can also be effectively accomplished with other pressure, temperature and accelerometer sensors. One of the advantages of using SAW devices is that they are totally passive thereby eliminating the requirement of a battery. For the implementation of tire monitor assembly 40, the changes in acceleration can also be used to generate sufficient electrical energy to power a silicon microcircuit. In this configuration, additional devices, typically piezoelectric devices, are used as a generator of electricity that can be stored in one or more conventional capacitors or ultra-capacitors. Naturally, other types of electrical generators can be used such as those based on a moving coil and a magnetic field etc. A PVDF piezoelectric polymer can also be used to generate electrical energy based on the flexure of the tire as described below.

FIG. 4 illustrates an absolute pressure sensor based on surface acoustic wave (SAW) technology. A SAW absolute pressure sensor 50 has an interdigital transducer (IDT) 51 which is connected to antenna 52. Upon receiving an RF signal of the proper frequency, the antenna induces a surface acoustic wave in the material 53 which can be lithium niobate, quartz, zinc oxide, or other appropriate piezoelectric material. As the wave passes through a pressure sensing area 54 formed on the material 53, its velocity is changed depending on the air pressure exerted on the sensing area 54. The wave is then reflected by reflectors 55 where it returns to the IDT 51 and to the antenna 52 for retransmission back to the interrogator. The material in the pressure sensing area 54 can be a thin (such as one micron) coating of rubber such as silicone rubber or other elastomeric material which serves to couple the air pressure to the surface acoustic wave device. The material of pressure sensing area 54 can either make the device more or less sensitive to air pressure changes depending on the properties of material.

In FIG. 4A, two additional sections of the SAW device, designated 56 and 57, are provided such that the air pressure affects sections 56 and 57 differently than pressure sensing area 54. This is achieved by providing three reflectors. The three reflecting areas cause three reflected waves to appear, 59, 60 and 61 when input wave 62 is provided. The spacing between waves 59 and 60, and between waves 60 and 61 provides a measure of the pressure. This construction of a pressure sensor may be utilized in the embodiments of FIGS. 1A-3 or in any embodiment wherein a pressure measurement by a SAW device is obtained.

There are many other ways in which the pressure can be measured based on either the time between reflections or on the frequency or phase change of the SAW device as is well known to those skilled in the art. FIG. 4B, for example, illustrates an alternate SAW geometry where only two sections are required to measure both temperature and pressure. This construction of a temperature and pressure sensor may be utilized in the embodiments of FIGS. 1A-3 or in any embodiment wherein both a pressure measurement and a temperature measurement by a single SAW device is obtained.

The fact that speed of sound on a piezoelectric material can be changed by pressure was first reported in Varadan et al "Local/Global SAW Sensors for Turbulence" referenced above. This, phenomenon has not been applied to solving pressure sensing problems within an automobile until now. The instant invention is

believed to be the first application of this principle to measuring tire pressure, oil pressure, coolant pressure, pressure in a gas tank, etc.

In some cases, a flexible membrane is placed loosely over the SAW device to prevent contaminants from affecting the SAW surface. The flexible membrane permits the pressure to be transferred to the SAW device without subjecting the surface to contaminants. Such a flexible membrane can be used in most if not all of the embodiments described herein.

A SAW temperature sensor 60 is illustrated in FIG. 5. Since the SAW material, such as lithium niobate, expands significantly with temperature, the natural frequency of the device also changes. Thus, for a SAW temperature sensor to operate, a material for the substrate is selected which changes its properties as a function of temperature, i.e., expands. Similarly, the time delay between the insertion and retransmission of the signal also varies measurably. Since speed of a surface wave is typically 100,000 times slower then the speed of light, usually the time for the electromagnetic wave to travel to the SAW device and back is small in comparison to the time delay of the SAW wave and therefore the temperature is approximately the time delay between transmitting electromagnetic wave and its reception.

An alternate approach as illustrated in FIG. 5A is to place a thermistor 62 across an interdigital transducer (IDT) 61, which is now not shorted as it was in FIG. 5. In this case, the magnitude of the returned pulse varies with the temperature. Thus, this device can be used to obtain two independent temperature measurements, one based on time delay or natural frequency of the device 60 and the other based on the resistance of the thermistor 62.

When some other property such as pressure is being measured by the device 65 as shown in FIG. 5B, two parallel SAW devices are commonly used. These devices are designed so that they respond differently to one of the parameters to be measured. Thus, SAW devices 66,67 can be designed to both respond to temperature and respond to pressure. However, SAW device 67, which contains a surface coating, will respond differently to pressure than SAW device 66. Thus, by measuring natural frequency or the time delay of pulses inserted into both SAW devices 66,67, a determination can be made of both the pressure and temperature, for example. Naturally, the device which is rendered sensitive to pressure in the above discussion could alternately be rendered sensitive to some other property such as the presence or concentration of a gas, vapor, or liquid chemical as described in more detail below.

An accelerometer that can be used for either radial or tangential acceleration in the tire monitor assembly of FIG. 3 is illustrated in FIGS. 6 and 6A. The design of this accelerometer is explained in detail in Varadan, V.K. et al "Fabrication, characterization and testing of wireless MEMS-IDT based microaccelerometers" referenced above.

A stud which is threaded on both ends and which can be used to measure the weight of an occupant seat is illustrated in FIGS. 7A-7D. The operation of this device was disclosed in U.S. patent application Ser. No. 09/849,558 wherein the center section of stud 101 is solid. It has been discovered that sensitivity of the device can be significantly improved if a slotted member is used as described in U.S. Pat. No. 5,539,236. FIG. 7A illustrates a SAW strain gage 102 mounted on a substrate and attached to span a slot 104 in a center section 105 of the stud 101. This technique can be used with any other strain-measuring device.

FIG. 7B is a side view of the device of FIG. 7A.

FIG. 7C illustrates use of a single hole 106 drilled off-center in the center section 105 of the stud 101. A single hole 106 also serves to magnify the strain as sensed by the strain gage 102. It has the advantage in that

strain gage 102 does not need to span an open space. The amount of magnification obtained from this design, however, is significantly less than obtained with the design of FIG. 7A.

To improve the sensitivity of the device shown in FIG. 7C, multiple smaller holes 107 can be used as illustrated in FIG. 7D.

In operation, the SAW strain gage 102 receives radio frequency waves from an interrogator 110 and returns electromagnetic waves via antenna 103 which are delayed based on the strain sensed by strain gage 102.

A SAW device can also be used as a wireless switch as shown in FIGS. 8A and 8B. FIG. 8A shows a surface 120 containing a projection 122 on top of a SAW device 121. Surface material 120 could be, for example, the armrest of an automobile, the steering wheel airbag cover, or any other surface within the passenger compartment of an automobile or elsewhere. Projection 122 will typically be a material which is capable of transmitting force to the surface of SAW device 121. As shown in FIG. 8B, a projection 123 may be placed on top of the SAW device 124. This projection 123 permits force exerted on the projection 122 to create an increased pressure on the SAW device 124. This increased pressure changes the time delay or natural frequency of the SAW wave traveling on the surface of material. Alternately, it can affect the magnitude of the retuned signal.

An alternate approach is to place a switch across the IDT 127 as shown in FIG. 8C. If switch 125 is open, then the device will not return a signal to the interrogator. If it is closed, than the IDT 127 will act as a reflector sending a single back to IDT 128 and thus to the interrogator. Alternately, a switch 126 can be placed across the SAW device. In this case, a switch closure shorts the SAW device and no signal is returned to the interrogator. For the embodiment of FIG. 8C, using switch 126 instead of switch 125, a standard reflector IDT would be used in place of the IDT 127.

Most SAW-based accelerometers work on the principle of straining the SAW surface and thereby changing either the time delay or natural frequency of the system. An alternate novel accelerometer is illustrated FIG. 9A wherein a mass 130 is attached to a silicone rubber coating 131 which has been applied the SAW device. Acceleration of the mass in FIG. 9 in the direction of arrow X changes pressure on the surface of the SAW device and thereby changes the natural frequency or the time delay of the device. By this method, accurate measurements of acceleration below 1 G are readily obtained. Furthermore, this device can withstand high deceleration shocks without damage. The device acts a similar manner as the pressure sensors described above where mass provides the source of pressure. FIG. 9B illustrates a more conventional approach where the strain in a beam 137 caused by the acceleration acting on a mass 136 is measured with a SAW strain sensor 135.

It is important to note that all of these devices have a high dynamic range compared with most competitive technologies. In some cases, this dynamic range can exceed 100,000. This is the direct result of the ease with which frequency and phase can be accurately measured.

A gyroscope, which is suitable for automotive applications, is illustrated in FIG. 10 and described in detail in V.K. Varadan's International Application No. WO 00/79217. This SAW-based gyroscope has applicability for the vehicle navigation, dynamic control, and rollover sensing among others.

Note that any of the disclosed applications can be interrogated by the central interrogator of this invention and can either be powered or operated powerlessly as described in general above. Block diagrams of three interrogators suitable for use in this invention are illustrated in FIGS. 11A- 11C. FIG. 11A illustrates a superheterodyne circuit and FIG. 11B illustrates a dual superheterodyne circuit. FIG. 11C operates as follows. During the burst time two frequencies, F1 and F1+F2, are sent by the transmitter after being generated by

mixing using oscillator Osc. The two frequencies are needed by the SAW transducer where they are mixed yielding F2 which is modulated by the SAW and contains the information. Frequency (F1+F2) is sent only during the burst time while frequency F1 remains on until the signal F2 returns from the SAW. This signal is used for mixing. The signal returned from the SAW transducer to the interrogator is F1+F2 where F2 has been modulated by the SAW transducer. It is expected that the mixing operations will result in about 12 db loss in signal strength.

FIG. 12 illustrates a central antenna mounting arrangement for permitting interrogation of the tire monitors for four tires and is similar to that described in U.S. Pat. No. 4,237,728. An antenna package 200 is mounted on the underside of the vehicle and communicates with devices 201 through their antennas as described above. In order to provide for antennas both inside (for example for weight sensor interrogation) and outside of the vehicle, another antenna assembly (not shown) can be mounted on the opposite side of the vehicle floor from the antenna assembly 200.

FIG. 12A is a schematic of the vehicle shown in FIG.12. The antenna package 200, which can be considered as an electronics module, contains a time domain multiplexed antenna array that sends and receives data from each of the five tires (including the spare tire), one at a time. It comprises a microstrip or stripline antenna array and a microprocessor on the circuit board. The antennas that face each tire are in an X configuration so that the transmissions to and from the tire can be accomplished regardless of the tire rotation angle.

A chemical sensor 250 similar to the sensor of FIG. 5B is illustrated in FIG. 13A for mounting in a vehicle trunk as illustrated in FIG. 13. The chemical sensor 250 is designed to measure carbon dioxide concentration through the mass loading effects as described in U.S. Pat. No. 4,895,017, with a polymer coating selected that is sensitive to carbon dioxide. The speed of the surface acoustic wave is a function of the carbon dioxide level in the atmosphere. Section 252 of the SAW device contains a coating of such a polymer and the acoustic velocity in this section is a measure of the carbon dioxide concentration. Temperature effects are eliminated through a comparison of the sonic velocities in sections 251 and 252 as described above.

Thus, when trunk lid 260 is closed and a source of carbon dioxide such as a child or animal is trapped within the trunk, the chemical sensor 250 will provide information indicating the presence of the carbon dioxide producing object to the interrogator which can then release the trunk lock permitting trunk to automatically open. In this manner, the problem of children and animals suffocating in closed trunks is eliminated.

A similar device can be distributed at various locations within the passenger compartment of vehicle along with a combined temperature sensor. If the car has been left with a child or other animal while owner is shopping, for example, and if the temperature rises within the vehicle to an unsafe level or, alternately, if the temperature drops below an unsafe level, then the vehicle can be signaled to take appropriate action which may involve opening the windows or starting the vehicle with either air conditioning or heating as appropriate. Thus, through these simple wireless powerless sensors, the problem of suffocation either from lack of oxygen or death from excessive heat or cold can all be solved in a simple, low-cost manner through using the same interrogator as used for other devices such as tire monitoring.

Additionally, a sensitive layer on a SAW can be made to be sensitive to other chemicals such as water vapor for humidity control or alcohol for drunk driving control. Similarly, the sensitive layer can be designed to be sensitive to carbon monoxide thereby preventing carbon monoxide poisoning. Many other chemicals can be sensed for specific applications such as to check for chemical leaks in commercial vehicles, for example.

Based on the frequency and power available, and on FCC limitations, SAW devices can be designed to permit transmission distances of up to 100 feet or more. Since SAW devices can measure both temperature and humidity, they are also capable of monitoring road conditions in front of and around a vehicle. Thus, a properly equipped vehicle can determine the road conditions prior to entering a particular road section if such SAW devices are embedded in the road surface or on mounting structures close to the road surface as shown at 279 in FIG. 14. Such devices could provide advance warning of freezing conditions, for example. Although at 60 miles per hour, such devices may only provide a one second warning, this can be sufficient to provide information to a driver to prevent dangerous skidding. Additionally, since the actual temperature and humidity can be reported, the driver will be warned prior to freezing of the road surface. SAW device 279 is shown in detail in FIG. 14A.

If a SAW device 283 is placed in a roadway, as illustrated in FIG. 15, and if a vehicle 290 has two receiving antennas 280 and 281, an interrogator can transmit a signal from either of the two antennas and at a later time, the two antennas will receive the transmitted signal from the SAW device. By comparing the arrival time of the two received pulses, the position of vehicle on a lane can precisely determined (since the direction from each antenna 280,281 to the SAW device 283 can be calculated). If the SAW device 283 has an identification code encoded into the returned signal generated thereby, then the vehicle 290 can determine, providing a precise map is available, its position on the surface of the earth. If another antenna 286 is provided, for example, at the rear of the vehicle 290 then the longitudinal position of the vehicle can also be accurately determined as the vehicle passes the SAW device 283. Of course the SAW device 283 need not be in the center of the road. Alternate locations for positioning of the SAW device 283 are on overpasses above the road and on poles such as 284 and 285 on the roadside. Such a system has an advantage over a competing system using radar and reflectors in that it is easier to measure the relative time between the two received pulses than it is to measure time of flight of a radar signal to a reflector and back. Such a system operates in all weather conditions and is known as a precise location system. Eventually such a SAW device 283 can be placed every tenth of a mile along the roadway or at some other appropriate spacing.

If a vehicle is being guided by a DGPS and accurate map system such as disclosed in U.S. Patent application Ser. No. 09/679,317, a problem arises when the GPS receiver system looses satellite lock as would happen when the vehicle enters a tunnel, for example. If a precise location system as described above is placed at the exit of the tunnel then the vehicle will know exactly where it is and can re-establish satellite lock in as little as one second rather than typically 15 seconds as might otherwise be required. Other methods making use of the cell phone system can be used to establish an approximate location of the vehicle suitable for rapid acquisition of satellite lock as described in G.M. Djuknic, R.E. Richton "Geolocation and Assisted GPS", Computer Magazine, February 2001, IEEE Computer Society.

More particularly, geolocation technologies that rely exclusively on wireless networks such as time of arrival, time difference of arrival, angle of arrival, timing advance, and multipath fingerprinting offer a shorter time-to-first-fix (TTFF) than GPS. They also offer quick deployment and continuous tracking capability for navigation applications, without the added complexity and cost of upgrading or replacing any existing GPS receiver in vehicles. Compared to either mobile-station-based, stand-alone GPS or network-based geolocation, assisted-GPS (AGPS) technology offers superior accuracy, availability, and coverage at a reasonable cost. AGPS for use with vehicles would comprise a communications unit with a partial GPS receiver arranged in the vehicle, an AGPS server with a reference GPS receiver that can simultaneously "see" the same satellites as the

communications unit, and a wireless network infrastructure consisting of base stations and a mobile switching center. The network can accurately predict the GPS signal the communication unit will receive and convey that information to the mobile, greatly reducing search space size and shortening the TTFF from minutes to a second or less. In addition, an AGPS receiver in the communication unit can detect and demodulate weaker signals than those that conventional GPS receivers require. Because the network performs the location calculations, the communication unit only needs to contain a scaled-down GPS receiver. It is accurate within about 15 meters when they are outdoors, an order of magnitude more sensitive than conventional GPS.

Because an AGPS server can obtain the vehicle's position from the mobile switching center, at least to the level of cell and sector, and at the same time monitor signals from GPS satellites seen by mobile stations, it can predict the signals received by the vehicle for any given time. Specifically, the server can predict the Doppler shift due to satellite motion of GPS signals received by the vehicle, as well as other signal parameters that are a function of the vehicle's location. In a typical sector, uncertainty in a satellite signal's predicted time of arrival at the vehicle is about ±5 μs, which corresponds to ±5 chips of the GPS coarse acquisition (C/A) code. Therefore, an AGPS server can predict the phase of the pseudorandom noise (PRN) sequence that the receiver should use to despread the C/A signal from a particular satellite— each GPS satellite transmits a unique PRN sequence used for range measurements—and communicate that prediction to the vehicle. The search space for the actual Doppler shift and PRN phase is thus greatly reduced, and the AGPS receiver can accomplish the task in a fraction of the time required by conventional GPS receivers. Further, the AGPS server maintains a connection with the vehicle receiver over the wireless link, so the requirement of asking the communication unit to make specific measurements, collect the results, and communicate them back is easily met. After despreading and some additional signal processing, an AGPS receiver returns back "pseudoranges"—that is, ranges measured without taking into account the discrepancy between satellite and receiver clocks—to the AGPS server, which then calculates the vehicle's location. The vehicle can even complete the location fix itself without returning any data to the server.

Sensitivity assistance, also known as modulation wipe-off, provides another enhancement to detection of GPS signals in the vehicle's receiver. The sensitivity-assistance message contains predicted data bits of the GPS navigation message, which are expected to modulate the GPS signal of specific satellites at specified times. The mobile station receiver can therefore remove bit modulation in the received GPS signal prior to coherent integration. By extending coherent integration beyond the 20-ms GPS data-bit period—to a second or more when the receiver is stationary and to 400 ms when it is fast-moving—this approach improves receiver sensitivity. Sensitivity assistance provides an additional 3-to-4-dB improvement in receiver sensitivity. Because some of the gain provided by the basic assistance—code phases and Doppler shift values—is lost when integrating the GPS receiver chain into a mobile phone, this can prove crucial to making a practical receiver.

Achieving optimal performance of sensitivity assistance in TIA/EIA-95 CDMA systems is relatively straightforward because base stations and mobiles synchronize with GPS time. Given that global system for mobile communication (GSM), time division multiple access (TDMA), or advanced mobile phone service (AMPS) systems do not maintain such stringent synchronization, implementation of sensitivity assistance and AGPS technology in general will require novel approaches to satisfy the timing requirement. The standardized solution for GSM and TDMA adds time calibration receivers in the field—location measurement units—that can monitor both the wireless-system timing and GPS signals used as a timing reference.

Many factors affect the accuracy of geolocation technologies, especially terrain variations such as hilly versus flat and environmental differences such as urban versus suburban versus rural. Other factors, like cell size and interference, have smaller but noticeable effects. Hybrid approaches that use multiple geolocation technologies appear to be the most robust solution to problems of accuracy and coverage.

AGPS provides a natural fit for hybrid solutions because it uses the wireless network to supply assistance data to GPS receivers in vehicles. This feature makes it easy to augment the assistance-data message with low-accuracy distances from receiver to base stations measured by the network equipment. Such hybrid solutions benefit from the high density of base stations in dense urban environments, which are hostile to GPS signals. Conversely, rural environments—where base stations are too scarce for network-based solutions to achieve high accuracy— provide ideal operating conditions for AGPS because GPS works well there.

SAW transponders can also be placed in the license plates 287 of all vehicles at nominal cost. An appropriately equipped automobile can then determine the angular location of vehicles in its vicinity. If a third antenna 286 is placed at the center of the vehicle front, then an indication of the distance to a license plate of a preceding vehicle can also be obtained as described above. Thus, once again, a single interrogator coupled with multiple antenna systems can be used for many functions. Alternately, if more than one SAW transponders is placed spaced apart on a vehicle and if two antennas are on the other vehicle, then the direction and position of the SAW vehicle can be determined by the receiving vehicle.

A general SAW temperature and pressure gage which can be wireless and powerless is shown generally at 300 located in the sidewall 310 of a fluid container 320 in FIG. 16. A pressure sensor 301 is located on the inside of the container 320 and the fluid temperature sensor 302 on the outside. The temperature measuring SAW 300 can be covered with an insulating material to avoid influence from the ambient temperature outside of the container 320.

A SAW load sensor can also be used to measure load in the vehicle suspension system powerless and wirelessly as shown in FIG. 17. FIG. 17A illustrates a strut 315 such as either of the rear struts of the vehicle of FIG. 17. A coil spring 320 stresses in torsion as the vehicle encounters disturbances from the road and this torsion can be measured using SAW strain gages as described in U.S. Pat. No. 5,585,571 for measuring the torque in shafts. This concept is also disclosed in U.S. Pat. No. 5,714,695. The use of SAW strain gages to measure the torsional stresses in a spring, as shown in FIG. 17B, and in particular in an automobile suspension spring has, to the knowledge of the inventors, not been heretofore disclosed. In FIG. 17B, the strain measured by SAW strain gage 322 is subtracted from the strain measured by SAW strain gage 321 to get the temperature compensated strain in spring 320.

Since a portion of the dynamic load is also carried by the shock absorber, the SAW strain gages 321 and 322 will only measure the steady or average load on the vehicle. However, additional SAW strain gages 325 can be placed on a piston rod 326 of the shock absorber to obtain the dynamic load. These load measurements can then be used for active or passive vehicle damping or other stability control purposes.

FIG. 18 illustrates a vehicle passenger compartment with multiple SAW temperature sensors 330. SAW temperature sensors are distributed throughout the passenger compartment, such as on the A-pillar, on the B-pillar, on the steering wheel, on the seat, on the ceiling, on the headliner, and on the rear glass. These sensors, which can be independently coded with different IDs and different delays, can provide an accurate measurement of the temperature distribution within the vehicle interior. Such a system can be used to tailor the heating and air conditioning system based on the temperature at a particular location in the passenger compartment. If this

system is augmented with occupant sensors, then the temperature can be controlled based on seat occupancy and the temperature at that location. If the occupant sensor system is based on ultrasonics than the temperature measurement system can be used to correct the ultrasonic occupant sensor system for the speed of sound within the passenger compartment. Without such a correction, the error in the sensing system can be as large as 20 percent.

In one case, the SAW temperature sensor can be made from PVDF film and incorporated within the ultrasonic transducer assembly. For the 40 kHz ultrasonic transducer case, for example, the SAW temperature sensor would return the several pulses sent to drive the ultrasonic transducer to the control circuitry using the same wires used to transmit the pulses to the transducer after a delay that is proportional to the temperature within the transducer housing. Thus a very economical device can add this temperature sensing function using much of the same hardware that is already present for the occupant sensing system. Since the frequency is low, PVDF could be fabricated into a very low cost temperature sensor for this purpose. Other piezoelectric materials could also be used.

Other sensors can be combined with the temperature sensors 330, or used separately, to measure carbon dioxide, carbon monoxide, alcohol, humidity or other desired chemicals as discussed above.

The SAW temperature sensors 330 provide the temperature at their mounting location to a processor unit 332 via an interrogator with the processor unit including appropriate control algorithms for controlling the heating and air conditioning system based on the detected temperatures. The processor unit can control, e.g., which vents in the vehicle are open and closed, the flow rate through vents and the temperature of air passing through the vents. In general, the processor unit can control whatever adjustable components are present or form part of the heating and air conditioning system.

As shown in FIG. 18, a child seat 334 is present on the rear vehicle seat. The child seat 334 can be fabricated with one or more RFID tags or SAW tags 336. The RFID tag(s) and SAW tag(s) can be constructed to provide information on the occupancy of the child seat, i.e., whether a child is present, based on the weight. Also, the mere transmission of waves from the RFID tag(s) or SAW tag(s) on the child seat would be indicative of the presence of a child seat. The RFID tag(s) and SAW tag(s) can also be constructed to provide information about the orientation of the child seat, i.e., whether it is facing rearward or forward. Such information about the presence and occupancy of the child seat and its orientation can be used in the control of vehicular systems, such as the vehicle airbag system. In this case, a processor would control the airbag system and would receive information from the RFID tag(s) and SAW tag(s) via an interrogator.

There are many applications for which knowledge of the pitch and/or roll orientation of a vehicle or other object is desired. An accurate tilt sensor can be constructed using SAW devices. Such a sensor is illustrated in FIG. 19A and designated 350. This sensor 350 utilizes a substantially planar and rectangular mass 351 and four supporting SAW devices 352 which are sensitive to gravity. Other properties can also be used for a tilt sensor such as the direction of the earth's magnetic field. SAW devices 352 are shown arranged at the corners of the planar mass 351, but it must be understood that this arrangement is a preferred embodiment only and not intended to limit the invention. A fifth SAW device 353 can be provided to measure temperature. By comparing the outputs of the four SAW devices 352, the pitch and roll of the automobile can be measured. This sensor 350 can be used to correct errors in the SAW rate gyros described above. If the vehicle has been stationary for a period of time, the yaw SAW rate gyro can initialized to 0 and the pitch and roll SAW gyros initialized to a value determined by the tilt sensor of FIG. 19.Many other geometries of tilt sensors utilizing one

or more SAW devices can now be envisioned for automotive and other applications. In particular, an alternate preferred configuration is illustrated in FIG. 19B where a triangular geometry is used. In this embodiment, the planar mass is triangular and the SAW devices 352 are arranged at the corners, although as with FIG. 19A, this is a non-limiting, preferred embodiment.

Either of the SAW accelerometers described above can be utilized for crash sensors as shown in FIG. 20. These accelerometers have a substantially higher dynamic range than competing accelerometers now used for crash sensors such as those based on MEMS silicon springs and masses and others based on MEMS capacitive sensing. As discussed above, this is partially a result of the use of frequency or phase shifts which can be easily measured over a very wide range. Additionally, many conventional accelerometers that are designed for low acceleration ranges are unable to withstand high acceleration shocks without breaking. This places practical limitations on many accelerometer designs so that the stresses in the silicon springs are not excessive. Also for capacitive accelerometers, there is a narrow limit over which distance, and thus acceleration, can be measured.

The SAW accelerometer for this particular crash sensor design is housed in a container 361 which is assembled into a housing 362 and covered with a cover 363. This particular implementation shows a connector 364 indicating that this sensor would require power and the response would be provided through wires. Alternately, as discussed for other devices above, the connector 364 can be eliminated and the information and power to operate the device transmitted wirelessly. Such sensors can be used as frontal, side or rear impact sensors. They can be used in the crush zone, in the passenger compartment or any other appropriate vehicle location. If two such sensors are separated and have appropriate sensitive axes, then the angular acceleration of the vehicle can be also be determined. Thus, for example, forward-facing accelerometers mounted in the vehicle side doors can used to measure the yaw acceleration of the vehicle. Alternately two vertical sensitive axis accelerometers in the side doors can be used to measure the roll acceleration of vehicle, which would be useful for rollover sensing.

Although piezoelectric SAW devices normally use rigid material such as quartz or lithium niobate, it is also possible to utilize polyvinylidene fluoride (PVDF) providing the frequency is low. A piece of PVDF film can also be used as a sensor of tire flexure by itself. Such a sensor is illustrated in FIG. 21 at 400. The output of flexure of the PVDF film can be used to supply power to a silicon microcircuit that contains pressure and temperature sensors. The waveform of the output from the PVDF film also provides information as to the flexure of an automobile tire and can be used to diagnose problems with the tire as well as the tire footprint in a manner similar to the device described in FIG. 3. In this case, however, the PVDF film supplies sufficient power to permit significantly more transmission energy to be provided. The frequency and informational content can be made compatible with the SAW interrogator described above such that the same interrogator can be used. The power available for the interrogator, however, can be significantly greater thus increasing the reliability and reading range of the system.

There is a general problem with tire pressure monitors as well as systems that attempt to interrogate passive SAW or electronic RFID type devices in that the FCC severely limits the frequencies and radiating power that can be used. Once it becomes evident that these systems will eventually save many lives, the FCC can be expected to modify their position. In the meantime, various schemes can be used to help alleviate this problem. The lower frequencies that have been opened for automotive radar permit higher power to be used and they could be candidates for the devices discussed above. It is also possible, in some cases, to transmit power

on multiple frequencies and combine the received power to boost the available energy. Energy can of course be stored and periodically used to drive circuits and work is ongoing to reduce the voltage required to operate semiconductors. The devices of this invention will make use of some or all of these developments as they take place.

If the vehicle has been at rest for a significant time period, power will leak from the storage capacitors and will not be available for transmission. However, a few tire rotations are sufficient to provide the necessary energy.

U.S. patent application Ser. No. 08/819,609 provides multiple means for determining the amount of gas in a gas tank. Using the SAW pressure devices of this invention, multiple pressure sensors can be placed at appropriate locations within a fuel tank to measure the fluid pressure and thereby determine the quantity of fuel remaining in the tank. This is illustrated in FIG. 22. In this example, four SAW pressure transducers 402 are placed on the bottom of the fuel tank and one SAW pressure transducer 403 is placed at the top of the fuel tank to eliminate the effects of vapor pressure within tank. Using neural networks, or other pattern recognition techniques, the quantity of fuel in the tank can be accurately determined from these pressure readings in a manner similar that described the '609 patent application. The SAW measuring device illustrated in FIG. 22A combines temperature and pressure measurements in a single unit using parallel paths 405 and 406 in the same manner as described above.

Occupant weight sensors can give erroneous results if the seatbelt is pulled tight pushing the occupant into the seat. This is particularly a problem when the seatbelt is not attached to the seat. For such cases, it has been proposed to measure the tension in various parts of the seatbelt. Using conventional technology requires that such devices be hard-wired into the vehicle complicating the wire harness. Using a SAW strain gage as described above, the tension in the seat belt can be measured without the requirement of power or signal wires. FIG. 23 illustrates a powerless and wireless passive SAW strain gage based device 502 for this purpose. There are many other places that such a device can be mounted to measure the tension in the seatbelt at one or at multiple places.

FIG. 24 illustrates another version of a tire temperature and/or pressure monitor 510. Monitor 510 may include at an inward end, any one of the temperature transducers or sensors described above and/or any one of the pressure transducers or sensors described above, or any one of the combination temperature and pressure transducers or sensors described above.

The monitor 510 has an elongate body attached through the wheel rim 513 typically on the inside of the tire so that the under-vehicle mounted antenna(s) have a line of sight view of antenna 515. Monitor 510 is connected to an inductive wire 512, which matches the output of the device with the antenna 515, which is part of the device assembly. Insulating material 511 surrounds the body and prevents electrical contact with the wheel rim 513.

The following discussion mentions other derivative or related inventions of wireless devices that contain transducers, and may be repetitive to some extent to the discussion above.

One embodiment of the invention is a temperature transducer coupled with appropriate circuitry which is capable of receiving power either inductively or through radio frequency energy transfer or even, and some cases, capacitively. Such temperature sensors may be used to measure the temperature inside the passenger compartment or outside of the vehicle. It can also be used to measure the temperature of some component(s) in the vehicle. A distinctive feature of this embodiment is that such temperature transducers are not hard-wired

into the vehicle and do not rely solely on batteries. Such temperature sensors have been used in other environments such as the monitoring of the temperature of domestic and farm animals for health monitoring purposes.

Wireless communication within a vehicle can be accomplished in several ways. The communication can be through the same path that supplies power to the device, or it can involve the transmission of waves that are received by another device in the vehicle. These waves can be either electromagnetic (microwave, infrared, etc) or ultrasonic. Many other types of transducers or sensors can be used in this manner. The distance to an object a vehicle can be measured using a radar reflector type RFID (Radio Frequency Identification) tag which permits the distance to the tag to be determined by the time of flight of radio waves. Another method of determining distance to an object can be through the use of ultrasound wherein the device is commanded to emit an ultrasonic burst and the time required for the waves to travel to a receiver is an indication of the displacement of the device from the receiver.

Although in most cases the communication will take place within the vehicle, and some cases such as external temperature transducers or tire pressure transducers, the source of transmission will be located outside of the compartment of the vehicle.

In one simple form, an embodiment of the invention can involve a single transducer and system for providing power and receiving information. An example of such a device would be an exterior temperature monitor which is placed outside of the vehicle and receives its power and transmits its information through the windshield glass. At the other extreme, a pair of parallel wires carrying high frequency alternating current can travel to all parts of the vehicle where electric power is needed. In this case every device could be located within a few inches of this wire pair and through an appropriately designed inductive pickup system, each device receives the power for operation inductively from the wire pair. In this case, all sensors and actuators on the vehicle could be powered by the inductive power transfer system. The communication with these devices could either be over the same system or, alternately, could be take place via RF or other similar communication system. If the communication takes place either by RF or over a modulated wire system, a protocol such as the Bluetooth protocol would be required. Other options include the Ethernet and token ring protocols.

The above system technology is frequently referred to as loosely coupled inductive systems. Such systems have heretofore been used for powering a vehicle down a track or roadway but have not been used within the vehicle. The loosely coupled inductive system makes use of high frequency (typically 10,000 Hz) and resonant circuits to achieve a power transfer approaching 99 percent efficiency. The resonant system is driven using a switching amplifier.

Every device that utilizes the loosely coupled inductive system would contain a microprocessor and thus would considered a smart device. This includes every light, switch, motor, transducer, sensor etc. Each device would thus have an address and would respond only to information containing its address.

It is contemplated that some devices will require more power than can be obtained instantaneously from the inductive, capacitive or radio frequency source. In such cases, batteries, capacitors or ultra-capacitors may be used directly associated with a particular device to handle peak power requirements. Such a system can also be used when the device is safety critical and there is a danger of disruption of the power supply during a vehicle crash, for example. In general the battery or capacitor would be charged when the device is not being powered.

In some cases, the sensing device may be purely passive and require no power. One such example is when an infrared or optical beam of energy is reflected off of a passive reflector to determine the distance to that reflector.

There are a variety of systems disclosed in several US patents wherein an attempt is made to monitor the pressure inside a rotating tire and to transmit this information to a display inside the vehicle. A preferred approach for monitoring the pressure within a tire is to instead monitor the temperature of the tire and to compare that temperature to the temperature of other tires on the vehicle. When the pressure within a tire decreases, this generally results in the tire temperature rising if the vehicle load is being carried by that tire. In the case where two tires are operating together at the same location such as on a truck trailer, just the opposite occurs. That is, the temperature of the fully inflated tire increases since it is now caring more load than the partially inflated tire.

Transducers exist that are capable measuring temperature within 0.25 degrees. This becomes a very sensitive measure, therefore, of the temperature of the tire is the sensor is placed where it has a clear view of the tire tread. The status of a tire can then be determined by comparing it to a mating tire on the vehicle. In the case of a truck trailer, the mating tire would typically be the adjacent tire on the same axle. In an automobile, the mating tire would be the other tire at the front or back of the vehicle. Thus the temperature of the two rear tires of a SUV can be compared and if one is hotter than the other than it can be assumed that if this temperature differential persists that the hotter tire is under inflated.

The same sensor can also warn of a potential delamination as has recently taken placed on many tires manufactured by Firestone. Long before the delamination causes a catastrophic tire failure, the tire begins to heat and this differential temperature can be measured and used to warn the driver of a pending problem. Similarly the delamination that frequently accompanies retreaded tires on large trucks can be predicted if the temperature of the tread of the vehicle is monitored

A temperature-measuring sensor based on infrared radiation can therefore be placed in a position where the tire surface can be monitored and the results transmitted over a wire or wirelessly to a desired location in the vehicle.

For those cases where it is deemed desirable to actually measure the pressure or temperature within a tire, a device can be placed within the tire to either measure the temperature or pressure and receive its operational power either inductively or through radio frequency. Heretofore inductively powered tire mounted sensors have been taken placed at very low frequencies, 100 Hz and no attempt has been made to specifically design the inductive pickup so that the efficiency of power transfer is high. In contrast, the present invention operates at much higher frequencies and approaches 99 percent efficiency. Additionally many systems have attempted to transmit tire pressure to the vehicle cab wirelessly with poor results due to the intervening metal surfaces of the vehicle. The preferred approach in the present invention is to transmit the information over the inductive power source wires.

Many transducers are available for monitoring pressure within a vehicle tire. Some transducers are based on measuring the pressure across the valve stem. Others use a calibrated pressurized chamber and measure the displacement of one surface of that container relative to another. This displacement can be measured by a variety of techniques including capacitance. Any of these systems can be used with the present invention.

The one disadvantage of an external temperature measuring system is that it can be prone to being occluded by snow, ice, and dirt. Therefore an alternate approach is to place a temperature sensor within the vehicle tire as with the pressure sensor. The resulting temperature measurement data can be then transmitted to the vehicle either inductively or by radio frequency, or other similar suitable method.

In many luxury cars, the seat subsystem is becoming very complicated. Seat manufacturers state that almost all warranty repairs are associated with the wiring and connectors associated with the seat. The reliability of seat systems can therefore the substantially improved and the incidence of failures or warranty repairs drastically reduced if the wires and connectors can be eliminated from the seat subsystem.

Today there are switches located on the seat for controlling the forward and backward, up and down, and rotation of the seat and seat back. These switches are connected to the appropriate motors by wires. Additionally many seats now contain an airbag that must communicate with a sensor located in the vehicle door. Additionally many occupant presence sensors and weight sensing systems are appearing on vehicle seats. Finally some seats contain heaters and cooling elements, vibrators, and other comfort and convenience devices that require wires and switches.

As an example let us now look at weight sensing. Under the teachings of this invention, silicon strain gage weight sensors can be placed on the bolts that secure each seat to the slide mechanism. These strain Gage subsystems can contain sufficient electronics and inductive pickup coils so as to receive their operational energy from a pair of wires appropriately placed beneath the seats. The seat weight measurements can then be superimposed on the power frequency or transmitted wirelessly using RF or other convenient wireless technology. Other weight sensing technologies such as bladders and pressure sensors or two-dimensional resistive deflection sensing mats can also be handled in a similar manner.

Other methods of seat weight sensing include measuring the deflection of a part of the seat or of the bolts that connect the seat to the seat slide. For example, the strain in a bolt can be readily determined using wire or silicon strain gages, optical fiber strain gages, time of flight of ultrasonic waves traveling through the strained bolt, or the capacitive change of two appropriately position capacitor plates.

Using the loosely coupled inductive system, power in excess of a kilowatt can be readily transferred to run seat position motors without use of directly connected wires. Naturally the switches can also be coupled into the inductive system without any direct wire connections and the switches, which now can be placed on the door armrest or on the seat as desired, can provide the information to control the seat motors. Additionally, since microprocessors will now the present on every motor and switch, the classical problem of the four-way seat system to control three degrees of freedom can be easily solved.

In current four way seat systems, when an attempt is made to vertically raise the seat, the seat also rotates. Similarly when an attempt is made to rotate the seat it also moves either up or down. This is because there are four switches to control three degrees of freedom and thus there is an infinite combination of switch settings for each seat position setting. This problem can be easily solved with an algorithm that translates the switch settings to the proper motor positions.

The positions of the seat, seatback, and headrest, can also be readily monitored without having direct wire connections to the vehicle. This can be down in numerous ways beginning with the encoder system that is currently in use and ending with simple RFID radar reflective tags that can be interrogated by a remote RFID tag reader. Based on the time of light of radar waves, the positions of all of the desired surfaces of the seat can be instantly determined wirelessly.

The airbag system currently involves a large number of wires that carry information and power to and from the airbag central processing unit. Some vehicles have sensors mounted in the front of the vehicle and many vehicles also have sensors mounted in the side doors. In addition there are sensors and an electronic control module mounted in the passenger compartment. All cars now have passenger and driver airbags and some vehicles have as many as eight airbags considering the side impact torso airbag and head airbags as well as knee bolster airbags.

To partially cope with this problem, there is a movement to connect all of the safety systems onto a single bus. Once again the biggest problem with the reliability of airbag systems is the wiring and connectors. By practicing the teachings of this invention, one single pair of wires can be used to connect all of the airbag sensors and airbags together and to do so without the use of connectors. Thus the reliability of the system is substantially improved and the reduced installation costs more than offsets the added cost of having a loosely coupled inductive network.

The steering wheel of an automobile is becoming more complex as more functions are incorporated utilizing switches and/or a mouse touch pad on the steering wheel. Many vehicles have controls for heating and air conditioning, cruise control, radio, as well as more. Additionally the airbag must have a very high quality connection so that it reliably deploys even when an accident is underway.

This has resulted in the use of clock spring ribbon cables that make all of the electrical connections between the vehicle and the rotating steering wheel. The ribbon cable must at least able to carry sufficient current to reliably initiate airbag apply even at very cold temperatures. This requires that the ribbon cable contain at least two heavy conductors to bring power to the airbag. Under the airbag network concept, a capacitor or battery is used within the airbag module and kept charged thereby significantly reducing the amount of current that must pass through the ribbon cable. Thus the ribbon cable can be kept considerably smaller.

An alternate and preferred solution uses the teachings of this invention to inductively couple the steering wheel with the vehicle thus eliminating all wires and connectors. All of the switch functions, control functions, and airbag functions are multiplexed on top of the inductive carrier frequency. This greatly simplifies the initial installation of the steering wheel onto the vehicle since the complicated ribbon cable is no longer necessary. Similarly, it reduces warranty repairs caused by people changing steering wheels without making sure that the ribbon cable is properly positioned.

More and more electrical functions are also being placed into vehicle doors. This includes window control switches and motors as well as seat control switches, airbag crash sensors, etc. As a result the bundle of wires that must pass through the door edge and through the A-pillar has become a serious assembly and maintenance problem in the automotive industry. Using the teachings of this invention, the loosely coupled inductive system could pass anywhere near the door and an inductive pickup system placed on the other side where it obtains power and exchanges information when the mating surfaces are aligned. If these surfaces are placed in the A-pillar, then sufficient power will be available even when the door is open. Alternately, a battery or capacitive storage system can be provided in the door and the coupling can exist through the doorsill, for example. This eliminates the need for wires to pass through the door interface and greatly simplifies the assembly and installation of doors. It also greatly reduces warranty repairs caused by the constant movement of wires at the door and car body interface.

A driver executing a lane change when there is another vehicle in his blind spot causes many accidents. As a result, several firms are developing blind spot monitors based on radar, optics, or passive infrared, to detect

the presence of a vehicle in the driver's blind spot and to warn the driver should he attempt such a lane change. These blind spot monitors are typically placed on the outside of the vehicle near or on side rear view mirror. Since the device is exposed to rain, salt, snow etc., there is a reliability problem resulting from the need to seal the sensor and to permit wires to enter the sensor and also the vehicle. Special wire, for example, should used to prevent water from wicking through the wire. These problems as well as similar problems associated with other devices which require electric power and which are exposed to the environment, such as forward mounted airbag crash sensors, can be solved utilizing and inductive coupling techniques of this invention.

A serious source of safety and reliability problems results from the flexible wire connections that are necessary between a truck and a trailer. The need for these flexible wire connections and their associated connector problems can be eliminated using the inductive coupling techniques of this invention. In this case the mere attachment of the trailer to the tractor automatically aligns an inductive pickup device on the trailer with the power lines imbedded in the fifth wheel.

Switches in general do not consume power and therefore they can be implemented wirelessly according to the teachings of this invention in many different modes. For a simple on off switch a one bit RFID tag similar to what is commonly used for protecting against shoplifting in stores with a slight modification can be easily implemented. The RFID tag switch would contain its address and a single accessible bit permitting the device to be interrogated regardless of its location in the vehicle without wires.

As the switch function becomes more complicated, additional power may be required and the options for interrogation become more limited. For a continuously varying switch, for example the volume control on a radio, it may be desirable to use a more complicated design where an inductive transfer of information is utilized. On the other hand, by using momentary contact switches that would set the one bit on only while the switch is activated and by using the duration of activation than volume control type functions can still be performed even though the switch is remote from the interrogator.

This concept then permits the placement of switches at arbitrary locations anywhere in the vehicle without regard to the placement of wires. Additionally, multiple switches can be easily used to control the same device or a single switch can control many devices.

For example, a switch to control the forward and rearward motion of the driver seat can be placed on the driver door mounted armrest and interrogated by RFID reader located in the headliner of the vehicle. The interrogator periodically monitors all RFID switches located in the vehicle which may number over 100. If the driver armrest switch is depressed and the switch bit is changed from 0 to 1, the reader knows based on the address or identification number of the switch that the driver intends to operate his seat in a forward or reverse manner. A signal is then sent over the inductive power transfer line to the motor controlling the seat and the motor is commanded to move the seat either forward based on one switch ID or backward based on another switch ID. Thus, the switch in the armrest would actually contained two identification RFIDs one for forward movement of seat and one for rearward movement of the seat. As soon the driver ceases operating the switch, the switch state returns to 0 and a command is sent to the motor to stop moving the seat.

By this process, all of the 100 or so switches and other simple sensors can become wireless devices and vastly reduced the number of wires in a vehicle and vastly increase the reliability and reduce warranty repairs.

In contrast to switches, lights require power. The power required generally exceeds that which can be easily transmitted by RF or capacitive coupling. For lights to become wireless, therefore, inductive coupling is required. Now, however, it is no longer necessary to have light sockets, wires and connectors. Each light bulb

will would be outfitted with an inductive pickup device and a microprocessor. The microprocessor processor listens to the information coming over the inductive pickup line and when it recognizes its address it activates an internal switch which turns on the light. The light bulb becomes a totally sealed, self-contained unit with no electrical connectors for connections to the vehicle. It is automatically connected by mounting in a holder and by the proximity which can be as far away as several inches, to the inductive power line. It has been demonstrated that power transfer efficiencies of up to 99 percent can be achieved by this system and power levels exceeding 1 kW can be transferred to a device.

This invention therefore considerably simplifies the mounting of lights in a vehicle since the lights are totally self-contained and not plugged into the vehicle power system. Problems associated with sealing the light socket from the environment disappear vastly simplifying the installation of headlights, for example, into the vehicle. The skin of the vehicle need not contain any receptacles for a light plug and therefore there is no need to seal the light bulb edges to prevent water from entering behind the light bulb. Thus the reliability of vehicle exterior lighting systems is vastly improved. Similarly, the ease with which light bulbs can be changed when they burn out is vastly simplified since the complicated mechanisms for sealing the light bulb into the vehicle are no longer necessary. Although headlights were discussed the same principles apply to all other lights mounted on a vehicle exterior.

Since it is contemplated that the main power transfer wire pair will travel throughout the automobile in a single branched loop, several light bulbs can be inductive inductively attached to the inductive wire power supplier by merely locating a holder for the sealed light bulb within a few inches of the wire. Once again no electrical connections are required.

Considered for example the activation of the right turn signal. The microprocessor associated with the turn switch on the steering column is programmed to transmit the addresses of the right front and rear turn light bulbs to turn them on. A fraction of a second later, the microprocessor sends a signal over the inductive power transfer line to turn the light bulbs off. This is repeated for as long as the turn signal switch is placed in the activation position for a right turn. The right rear turn signal light bulb receives a message with its address and a bit set for light to be turned on and it responds by so doing and similarly the when the signal is received for turning the light off. Once again all such transmissions occurred over a single power and information inductive line and no wire connections are made to the light bulb. In this example, all power and information is transferred inductively.

The RFID technology is particularly applicable to keyless entry. Instead of depressing a button on a remote vehicle door opener, the owner of vehicle need only carry an RFID card in his pocket. Upon approaching the vehicle door, the reader located in the vehicle door, activates the circuitry in the RFID card and receives the identification number checks it and unlocks the vehicle if the code matches. Simultaneously, the vehicle now knows that this is driver No. 3, for example, and automatically sets the seat position, headrest position, mirror position, radio stations temperature controls and all other drivers specific functions including the positions of the petals to adapt vehicle to the particular driver. When the driver sits in the seat no ignition key is necessary and by merely depressing a switch which can be located anywhere in the vehicle, on the armrest for example, the vehicle motor starts. Naturally the switch can be wireless and the reader or interrogator which initially read the operators card can be connected inductively to the vehicle power system.

A frequent cause of accidents is the sudden freezing of roadways or bridge surfaces when the roadway is wet and temperatures are near freezing. Sensors exist that can detect the temperature of the road surface

within less than one degree. These sensors should be mounted in locations where they have a clear view of the road and thus they are susceptible to assault from rain, snow, ice, salt etc. The reliability of connecting these sensors into the vehicle power and information system is thus compromised. Using the teachings of this invention, black ice warning sensors can be mounted externally to the vehicle and coupled into the vehicle power and information system inductively, thus removing a significant cause of failure of such sensors.

Similar sensors can also used to detect the type of roadway on which the car is traveling. Gravel roads, for example, have typically a lower effective coefficient of friction than do concrete roads. Knowledge of the road characteristics can provide useful information to the vehicle control system and, for example, warn the driver when the speed driven is above what is safe for the road conditions.

Many new sensors are now being adapted to an automobile to increase the safety, comfort and convenience of vehicle occupants. Each of the sensors currently requires separate wiring for power and information transfer. Under the teachings of this invention these separate wires would become unnecessary and sensors could be added at will to the automobile at any location within a few inches of the inductive power line system. Even sensors that were not contemplated by the vehicle manufacturer can be added later with a software change to the appropriate vehicle CPU.

Such sensors include heat load sensors that measure the sunlight coming in through the windshield and adjust the environmental conditions inside the vehicle to compensate. Seatbelt sensors that indicate that the seatbelt is buckled can now also use RFID technology. Door open or door ajar sensors that also can use the RFID technology and would not even need to be placed near an inductive power line. Gas tank fuel level and other fluid level sensors which do not require external power and now possible thus eliminating any hazard of sparks igniting the fuel in the case of a rear impact accident which ruptures the fuel tank, for example. Capacitive proximity sensors that measure the presence of a life form within a few meters of the automobile can be coupled wirelessly to the vehicle. Cameras or other vision or radar sensors that can be mounted external to the vehicle and not require unreliable electrical connections to the vehicle power system permitting such sensors to be totally sealed from the environment are also now possible. Such sensors can be based on millimeter wave radar, passive or active infrared, or optical or any other portion of the electromagnetic spectrum that is suitable for the task. Radar or ultrasonic backup sensors or rear impact anticipatory sensors also are now feasible with significantly greater reliability.

Immediately above, the use of radio frequency to interrogate an RFID tag is discussed. Naturally other forms of electromagnetic radiation are possible. For example, an infrared source can illuminate an area inside the vehicle and a CMOS camera can receive reflections from corner cube reflectors located on objects that move within the vehicle. These objects would include items such as the seat, seatback, and headrest. Through this technique the time of flight of the modulated IR radiation can be measured to each of the corner cube reflectors and the distance to the reflector thereby determined.

The above discussion has concentrated on applications primarily inside of the vehicle. There are also a significant number of applications concerning the interaction of a vehicle with its environment. Here we may deviate from the primary premise of this invention which is that the device that we are concerned with be either powerless in sense that no power is required other than perhaps that which can be obtained from a radio frequency signal or a powered device and where the power is obtained through induction coupling.

When looking exterior to the vehicle, devices that interact vehicle may be located sufficiently far away that they will require power and that power cannot be obtained from the automobile. In the discussion below we

will consider two types of such devices, the first type which does not require infrastructure-supplied power and the second which does.

A rule of thumb is that an RFID tag that is located more than one meter away from the reader or interrogator must have a battery. Exceptions to this involve cases where the only information that is transferred is due to the reflection off of a radar reflector type device. For those cases a purely passive RFID can be five and sometimes more meters away from the interrogator. Nevertheless we shall assume that if the device is more than a few meters away that the device must contain some kind of external power supply.

The first interesting application is a low-cost form of adaptive cruise control or forward collision avoidance system. In this case a purely passive RFID tag would be placed on every rear license plate in a particular area such as a state. The subject vehicle would contain two readers, one on the forward left side of the vehicle and one on the forward right side. Upon approaching the rear of a car having the RFID license plate, the interrogators in the vehicle would be able to determine the distance, by way of reflected signal time of flight, from each reader to the license plate transducer. If the license plate RFID is passive than we are probably limited to a 5 meter range. Nevertheless, this will be sufficient to determine that there is a vehicle in front of or to the right or left side of subject vehicle. If the relative velocity of the two vehicles is such that a collision will occur, the subject vehicle can automatically have its speed altered so as to prevent the collision, typically a rear end collision.

Systems are under development which will permit an automobile to determine its location absolutely on the surface of the earth. These systems are being developed in conjunction with intelligent transportation systems. Such location systems are frequently based on differential GPS (DGPS). One problem with such systems is that the appropriate number of GPS satellites is not always within view of the automobile. For such cases it is necessary to have an earth-based system which will provide the information to the vehicle permitting it to absolutely locate itself within a few centimeters. One such system can involve the use of RFID tags placed above, adjacent or below the surface of the highway.

For the cases where the RFID tag are located more than a few meters from the vehicle a battery will probably be required and this will be discussed below. For the systems without batteries, such as placing the RFID tag in the concrete, once again having two readers located one on each side of the vehicle, the location of the tag embedded in the concrete can be precisely determine based on the time of flight of the radar pulse from the reader to the tag and back. Using this method the precise location of the vehicle relative to the tag within a few centimeters can be readily determined and since the position of the tag will be absolutely known by virtue of an in vehicle resident digital map, the position of the vehicle can be absolutely determined regardless of where the vehicle is. For example if the vehicle is in a tunnel then it will know precisely its location from the RFID pavement embedded tags.

It is also possible to determine the relative velocity of the vehicle relative to the RFID tag using the Doppler effect based on the reflected signals. For tags located on license plates the closing velocity of the two vehicles can be determined and for tags located in or adjacent to the highway pavement once again the velocity of the vehicle can be readily determined. Naturally the velocity can in both cases the determined based on differentiating two distance measurements.

In many cases it will be necessary to provide power to the RFID tag since the distance to the vehicle will exceed a few meters. This is currently being used in reverse for automatic tolling situations where the RFID tag is located on the vehicle and interrogated using readers located at the toll both.

When the RFID tag is to be interrogated by vehicle-mounted readers is more than a few meters from the vehicle, the tag must be supplied with power. This power can come from a variety of sources including a battery which is part of the device, direct electrical connections to a ground wire system, solar batteries, or inductive energy transfer from a power line.

For example, if an RFID tag were to the placed on a light post in downtown Manhattan, sufficient energy could be obtained from an inductive pickup from the wires used to power the light to recharge a battery in the RFID. Thus when the lights are turned on at night, the RFID battery could be recharged sufficiently to provide power for operation 24 hours a per day. In other cases, a battery would be included in the device and replacement of the battery would be necessitated periodically perhaps once every two years.

An alternate approach to having a vehicle transmit a pulse to the tag and wait for a response would be to have the tag periodically broadcast a few waves of information at precise timing increments. Then, once again, the vehicle with two receivers could locate itself accurately relative to the earth-based transmitter.

For example, in downtown Los Angelus it would be difficult to obtain information from satellites that are constantly blocked by tall buildings. Nevertheless, inexpensive transmitters could be placed on a variety of lampposts that would periodically transmit a pulse to all vehicles in the vicinity. Such a system could be based on a broadband micropower impulse radar system as disclosed in several U.S. patents. Alternately, a narrow band signal could be used.

Once again although radar type microwave pulses have been discussed, other portions of the electromagnetic spectrum could be utilized. For example, a vehicle could send a beam of modulated infrared toward infrastructure-based devices such as poles which contain corner reflectors. The time of flight of IR radiation from the vehicle to the reflectors can be accurately measured and since the vehicle would know, based on accurate maps, where the reflector is located there was the little opportunity for an error.

Many changes, modifications, variations and other uses and applications of the subject invention will now become apparent to those skilled in the art after considering this specification and the accompanying drawings which disclose the preferred embodiments thereof. All such changes, modifications, variations and other uses and applications which do not depart from the spirit and scope of the invention are deemed to be covered by the invention which is limited only by the following claims.

Claims

1. A valve cap for monitoring at least one of pressure and temperature of a tire having a valve stem including a valve assembly having a valve pin, comprising:

a body adapted to mate with a valve stem of the tire and define a chamber upon mating with the valve stem;

means arranged in said body and adapted to depress the valve pin upon mating of said body with the valve stem to open the valve assembly and enable flow communication between an interior of the tire and said chamber; and

at least one SAW sensor arranged in said chamber for receiving a signal and returning a signal modified by virtue of at least one of the temperature and pressure of the tire.

2. The valve cap of claim 1, wherein said at least one SAW sensor is arranged to function as an absolute pressure-measuring device.

3. The valve cap of claim 1, further comprising a flexible membrane arranged in said chamber, said at least one SAW sensor being mounted on said membrane such that said at least one SAW sensor is arranged to function as a differential pressure-measuring device.

4. The valve cap of claim 1, wherein said at least one SAW sensor is electrically connected to said body such that upon mating of said body with the valve stem, the valve stem serves as an antenna for transmitting radio frequency electromagnetic signals from said at least one SAW sensor.

5. A valve stem assembly for a tire, comprising:

an elongate metallic valve stem;

a body attached to a lower end of said valve stem; and

a sensor unit arranged in said body, said sensor unit comprising a capsule having a chamber, a passageway for providing flow communication between said chamber and an interior of the tire and a plurality of SAW sensors arranged in said chamber.

6. The valve stem assembly of claim 5, further comprising a coating of resilient material around said valve stem and a metal conductive ring attached to said valve stem.

7. The valve stem assembly of claim 5, wherein said sensor unit further comprises a rigid membrane dividing said chamber into first and second compartments, a first one of said SAW sensors being arranged in said first compartment which is in flow communication with the interior of the tire and a second one of said SAW sensors being arranged in said second compartment whereby said first SAW sensor functions as a pressure sensor and said second SAW sensor function as a temperature sensor.

8. The valve stem assembly of claim 5, wherein said sensor unit further comprises a flexible membrane dividing said chamber into first and second compartments, a first one of said SAW sensors being attached to said flexible membrane, said membrane forming a part of said first compartment which is in flow communication with the interior of the tire and a second one of said SAW sensors being arranged in said second compartment, not attached to said membrane whereby said first SAW sensor functions as a pressure sensor and said second SAW sensor function as a temperature sensor.

9. A tire with integral monitoring system, the tire including two spaced beads comprising steel wire, a tread, sidewalls, an innerliner and plies, comprising

a tire monitor fixed opposite the tread, said tire monitor including a plurality of SAW sensors, a first one of said SAW sensors being arranged to measure at least one of tangential and radial acceleration.

10. The tire of claim 9, wherein said first SAW sensors is arranged to measure tangential and/or radial acceleration.

11. The tire of claim 9, wherein a second one of said SAW sensors is arranged to measure pressure of the tire.

12. The tire of claim 9, wherein a second one of said SAW devices is arranged to measure temperature of the tire.

13. In a wheel rim for mounting a tire, an integral monitoring system comprising:

an elongate body extending through the wheel rim from an inward side of the wheel rim to an outward side of the wheel rim;,

a transducer arranged on an inward end of said body, said transducer being arranged to provide a measurement of at least one of the temperature and pressure in a tire when a tire is mounted on the wheel rim;

an antenna arranged on an outward end of said body; and

an inductive wire coupling said transducer to said antenna to enable transmission of a signal related to the measurement provided by said transducer.

14. The wheel rim of claim 13, further comprising insulating material arranged over said body to prevent contact between said body and the wheel rim.

15. A SAW sensor, comprising:

a substrate made of a material on which a wave is capable of traveling;

an interdigital transducer arranged in connection with said substrate;

an antenna coupled to said interdigital transducer;

at least one reflector spaced from said interdigital transducer; and

at least one coating of a material sensitive to pressure arranged on said substrate between said interdigital transducer and said at least one reflector such that the sensor provides a measurement of pressure.

16. The sensor of claim 15, wherein said at least one coating is an elastomeric material.

17. The sensor of claim 15, wherein said at least one coating is made of at least one polymer.

18. The sensor of claim 15, wherein said at least one reflector comprises a plurality of reflectors and said at least one coating comprises a plurality of coatings, one of said coatings being arranged immediately between said interdigital transducer and a proximate one of said reflectors and additional ones of said coatings being arranged between adjacent one of said reflectors.

19. The sensor of claim 15, wherein said at least one reflector comprises two reflectors and said substrate is made of a material which changes as a function of temperature, said interdigital transducer being arranged between said reflectors such that the sensor provides a measurement of both pressure and temperature.

20. The sensor of claim 15, further comprising a flexible membrane arranged over the sensor.

21. A SAW sensor, comprising:

a substrate made of a material on which a wave is capable of traveling and which changes as a function of temperature;

an interdigital transducer arranged in connection with said substrate;

an antenna coupled to said interdigital transducer; and

at least one reflector arranged on said substrate spaced from said interdigital transducer such that the sensor provides a measurement of temperature.

22. A SAW sensor, comprising:

a substrate made of a material on which a wave is capable of traveling and which changes as a function of temperature;

a first interdigital transducer arranged on said substrate;

an antenna coupled to said first interdigital transducer; and

a thermister arranged on said substrate spaced from said first interdigital transducer such that the sensor provides a measurement of temperature.

23. A SAW sensor, comprising:

a substrate made of a material on which a wave is capable of traveling;

first and second interdigital transducers arranged on said substrate;

first and second antennas coupled to said first and second interdigital transducers respectively; and

first and second reflectors spaced from said first and second interdigital transducers respectively, such that two properties of said substrate are measured.

24. The sensor of claim 23, further comprising a coating of a material sensitive to pressure arranged on said substrate between said first interdigital transducer and said first reflector.

25. The sensor of claim 24, wherein said coating comprises at least one polymer.

26. The sensor of claim 24, wherein said coating comprises at least one elastomeric material.

27. The sensor of claim 23, further comprising a material arranged on said substrate which is sensitive to the presence or concentration of a gas, vapor, or liquid chemical.

28. The sensor of claim 23, further comprising a coating of a material sensitive to carbon dioxide arranged on said substrate between said first interdigital transducer and said first reflector.

29. A SAW sensor, comprising:

a substrate made of a material on which a wave is capable of traveling;

an interdigital transducer arranged in connection with said substrate;

an antenna coupled to said interdigital transducer;

at least one reflector spaced from said interdigital transducer; and

at least one coating of a material sensitive to carbon dioxide arranged on said substrate between said interdigital transducer and said at least one reflector such that the sensor provides a measurement of the presence of carbon dioxide.

30. A vehicle comprising a trunk and said sensor of claim 29 arranged in an interior of said trunk.

31. The vehicle of claim 30, further comprising an automatic trunk opening device coupled to said sensor such that upon said sensor detecting carbon dioxide in said interior of said trunk indicative of the presence of a life form, said automatic trunk opening device opens said trunk.

32. The vehicle of claim 31, further comprising an interrogator for interrogating said sensor and being coupled to said automatic trunk opening device.

33. A switch for a vehicle, comprising:

a SAW sensor having a substrate, an interdigital transducer arranged on said substrate and a reflector arranged on said substrate spaced from said interdigital transducer; and

a material sheet including a projection in engagement with said substrate in a space between said interdigital transducer and said reflector such that pressure on said substrate is transferred by said projection to said substrate.

35. A switch for a vehicle, comprising:

a SAW sensor having a substrate, an interdigital transducer arranged on said substrate, a reflector arranged on said substrate spaced from said interdigital transducer and a projection arranged on said substrate between said interdigital transducer and said reflector; and

a material sheet arranged in engagement with said projection such that pressure on said substrate is transferred by said projection to said substrate.

36. An accelerometer, comprising:

a SAW sensor having a substrate, an interdigital transducer arranged on said substrate, a reflector arranged on said substrate spaced from said interdigital transducer;

a rubber coating applied to said substrate between said interdigital transducer and said reflector; and

an acceleration-sensing mass arranged on said coating whereby acceleration of said mass changes pressure on said substrate.

37. The accelerometer of claim 36, wherein said rubber coating is a silicone rubber coating.

38. A method for operating an interrogator for interrogating at least one SAW sensor, comprising the steps of:

generating and transmitting two frequencies, F1 and F1+F2, from the interrogator during a burst time;

continuing transmission of frequency F1 after the burst time until a frequency F2 is received from the at least one SAW sensor;

receiving the two frequencies at the at least one SAW sensor; and

mixing the two frequencies to yield a frequency F2 which is modulated by the at least one SAW sensor and contains the information about the measurement being performed by the at least one SAW sensor.

39. The method of claim 38, wherein the two frequencies are generated using an oscillator and a mixer.

40. A tire monitoring system for a vehicle, comprising:

an antenna package comprising a microstrip or stripline antenna array; and

a SAW sensor associated with each tire and including an antenna adapted to receive data from and transmit data to said antenna array.

41. The system of claim 40, wherein antennas of said antenna array which face each tire are in an X configuration such that the transmissions to and from the tires can be accomplished regardless of tire rotation angle.

42. A method for monitoring tire temperature and pressure, comprising the steps of:

mounting sensors in positions to obtain a reading of the temperature and/or pressure of tires, the sensors being sensitized to react to a transmission at a particular frequency,

mounting an interrogator on the vehicle adapted to receive communications from the sensors,

periodically sending a signal at the frequency to which the sensors are sensitized causing the sensors to respond and transmit a signal containing the temperature and/or pressure of the associated tire, and

processing the signals from the sensors to obtain an indication of the temperature and/or pressure of the tires.

43. The method of claim 42, further comprising the step of analyzing the temperature and/or pressure of the tires to determine if the tires are deflated, experiencing or about to experience tread separation or are overheating.

44. The method of claim 42, further comprising the step of notifying the driver or displaying indicia to the driver of the condition of the tires.

45. The method of claim 42, wherein at least one of the sensors is mounted to a valve stem of a tire.

46. The method of claim 42, further comprising the step of providing the interrogator with a plurality of antennas spaced apart from one another such that a comparison of the signal from the sensors enables the location of each of the sensors to be approximately determined.

47. The method of claim 42, wherein the sensors use surface acoustic wave technology wherein a radio frequency waves is converted into an acoustic wave which then travels on the surface of a material whereby the acoustic wave is modified based on a state being measured by the sensor and the modified wave is sensed by one or more IDT transducers and converted back to a radio frequency wave which is used to excite an antenna for transmitting the wave to interrogator.

48. The method of claim 42, further comprising the step of positioning the interrogator relative to the sensors such that the distance between each of the sensors and the interrogator is different.

49. A system for controlling deployment of an occupant restraint device in a vehicle, comprising

acceleration sensors for measuring accelerations of the vehicle or a part thereof, each of said sensors including a receiving unit for receiving a radio frequency signal, first conversion means for converting the radio frequency signal into an acoustic wave, means for causing the acoustic wave to be modified based on the measured acceleration, second conversion means for converting the modified acoustic wave into a radio frequency signal, and a transmission unit for transmitting the radio frequency signal; and,

at least one interrogator structured and arranged to transmit and receive radio frequency signals such that said at least one interrogator receives the radio frequency signals transmitted by said acceleration sensors and processes the signals to determine whether the vehicle is experiencing a crash requiring deployment of the occupant restraint device.

50. The system of claim 49, wherein at least one of said sensors is arranged in a front or rear crush zone of the vehicle.

51. The system of claim 49, wherein at least one of said sensors is arranged in a door of the vehicle.

52. The system of claim 49, wherein at least one of said sensors is arranged in a passenger compartment of the vehicle.

53. The system of claim 49, wherein said sensor comprises a substrate, said means for causing the acoustic wave to be modified based on the measured acceleration comprising a rubber coating applied to said substrate and an acceleration-sensing mass arranged on said coating whereby acceleration of said mass changes pressure on said substrate.

54. The system of claim 53, wherein said rubber coating is a silicone rubber coating.

55. A system for controlling access to a vehicle, comprising

a portable card containing a SAW identification system including a receiving unit for receiving a radio frequency signal, first conversion means for converting the radio frequency signal into an acoustic wave, means for modifying the acoustic wave, second conversion means for converting the modified acoustic wave into a radio frequency signal, and a transmission unit for transmitting the radio frequency signal; and

an interrogator arranged on the vehicle and structured and arranged to transmit and receive radio frequency signals such that said interrogator receives the radio frequency signal transmitted by said portable card and processes the signal to determine whether the signal is identical to a signal indicative of an authorized user of the vehicle.

56. The system of claim 55, further comprising a processor coupled to said interrogator for controlling locks on the vehicles based on the determination of whether the signal is identical to a signal indicative of an authorized user of the vehicle.

57. The system of claim 55, further comprising a processor coupled to said interrogator for controlling locks on the vehicles based on the determination of whether the signal is identical to a signal indicative of an authorized user of the vehicle, a distance between said portable card and the vehicle and the presence or absence of an occupant in the vehicle.

58. The system of claim 55, further comprising a processor coupled to said interrogator for controlling ignition of the vehicle based on the determination of whether the signal is identical to a signal indicative of an authorized user of the vehicle.

59. A tire monitoring device, comprising:

an accelerometer for measuring acceleration of a tread of the tire adjacent said sensor means; and

a processor coupled to said sensor means and said accelerometer for receiving the measured pressure, temperature and acceleration and determining whether the tire is at a non-optimal condition.

60. The device of claim 59, wherein said processor measures a length of time that a tread portion is in contact with the road surface such that a diameter of the tire footprint on the road is obtained, the diameter of the tire footprint being analyzed to determine whether the tire is at a non-optimal condition.

61. A tire monitoring device, comprising

means for monitoring the curvature of the tire as it rotates; and

means for correlating the curvature of the tire into an indication of an operational state of the tire.

62. The device of claim 61, wherein said monitoring means comprise a sensor mounted inside the tire at its largest diameter.

63. The device of claim 62, wherein said sensor is structured and arranged to measure mechanical strain.

64. The device of claim 63, wherein said correlation means comprise a processor for determining a ratio of a time in which said sensor indicates constant strain and a time in which said sensor indicates increased stretch.

65. The device of claim 62, wherein said sensor is structured and arranged to measure acceleration in any one axis.

66. The device of claim 65, wherein said correlation means comprise a processor for analyzing a time of zero acceleration in relation to a time of non-zero acceleration.

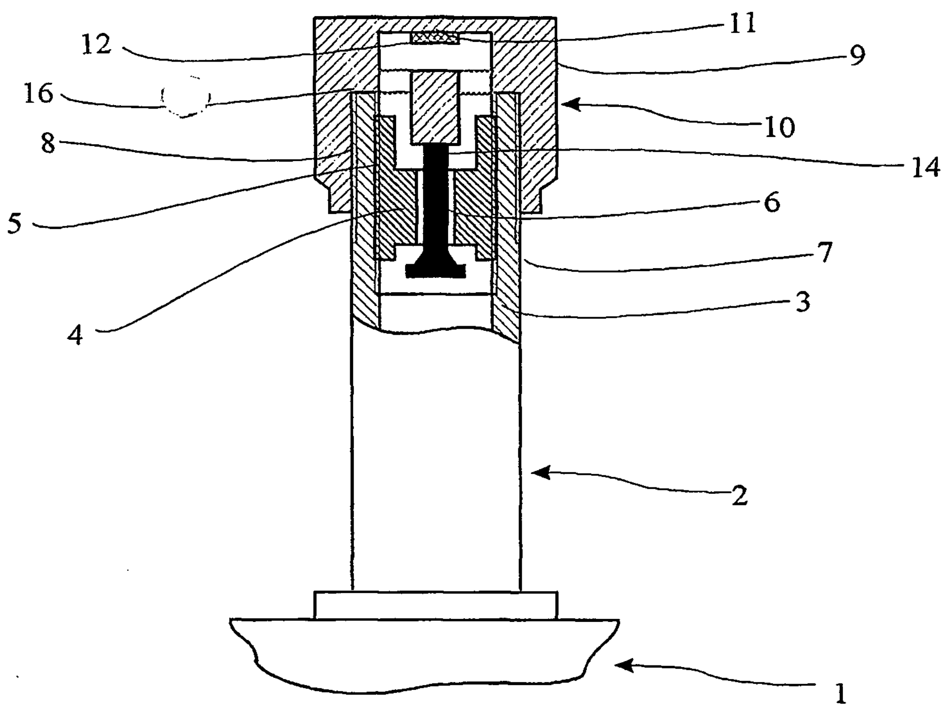


FIG. 1A

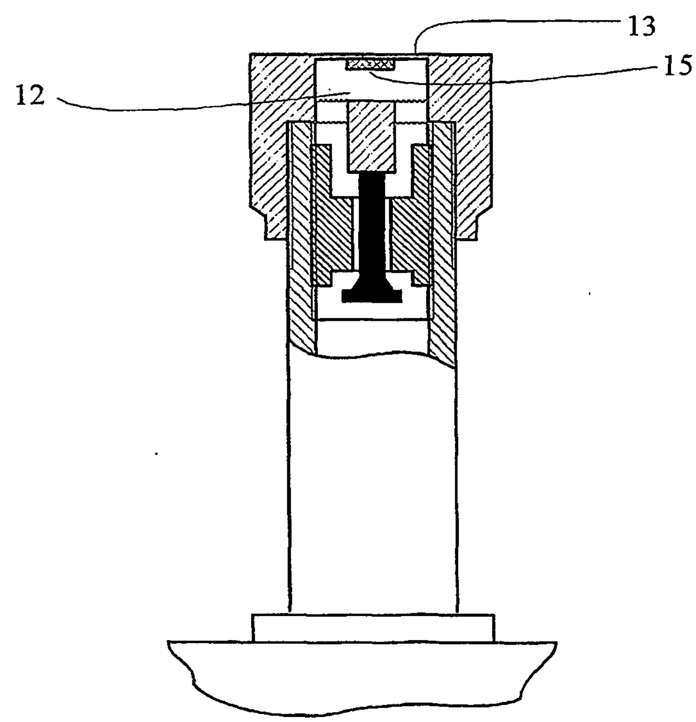


FIG. 1B

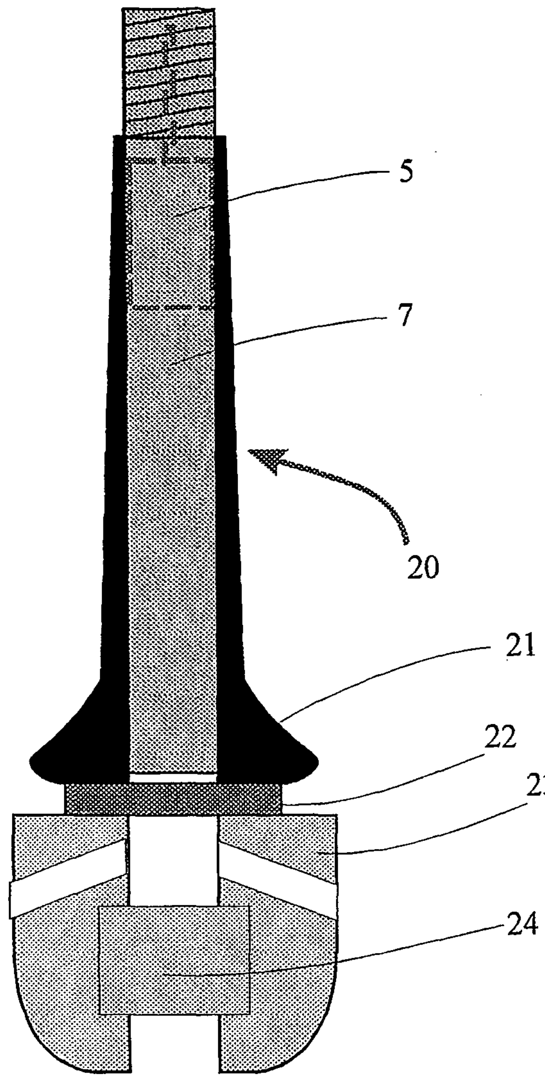


FIG. 2

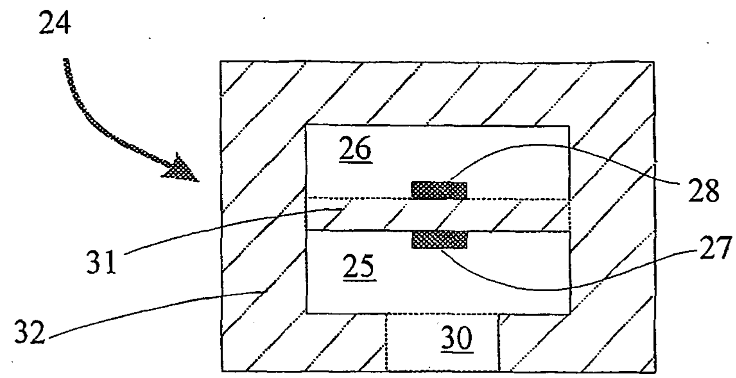


FIG. 2A

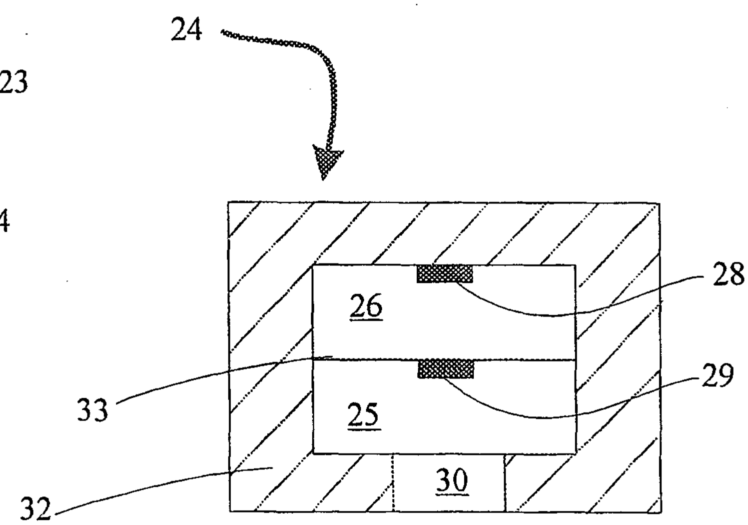


FIG. 2B

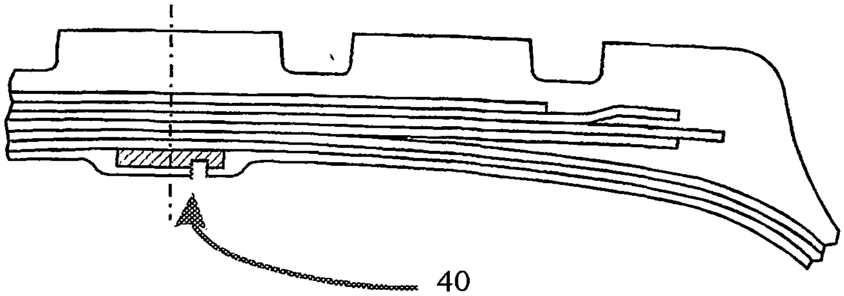


FIG. 3A

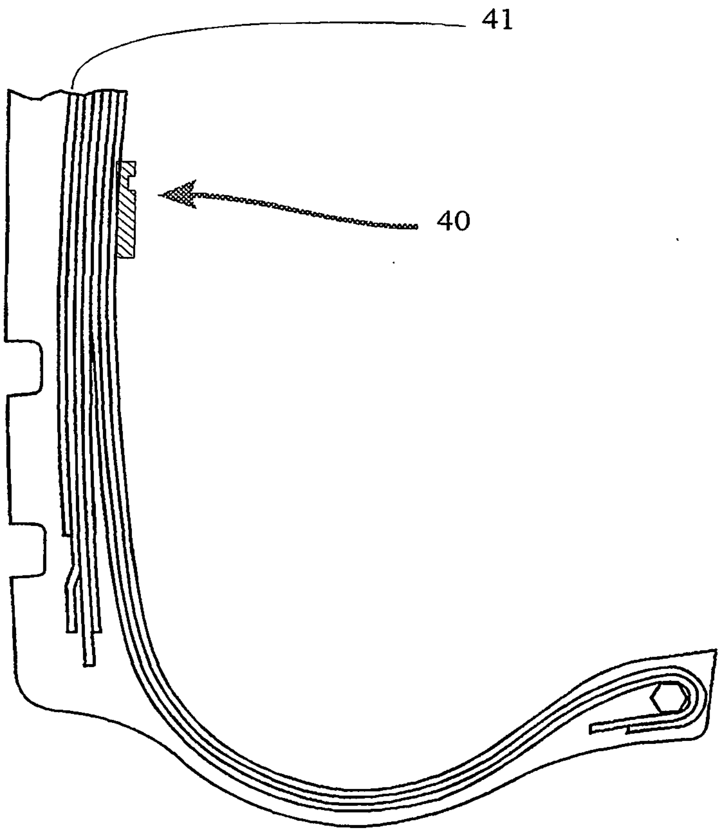


FIG. 3

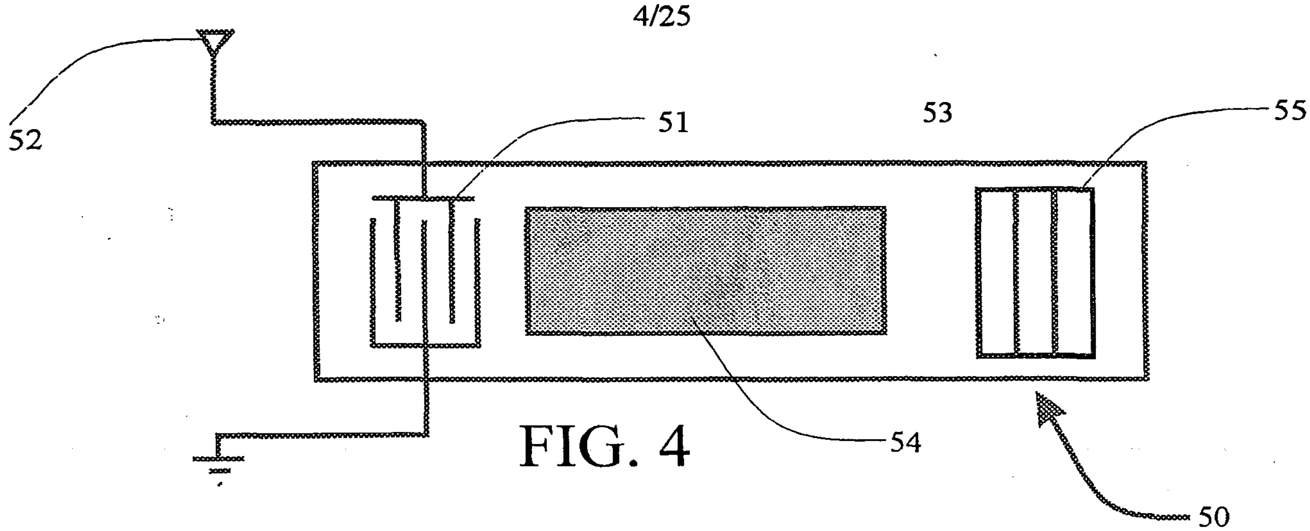


FIG. 4

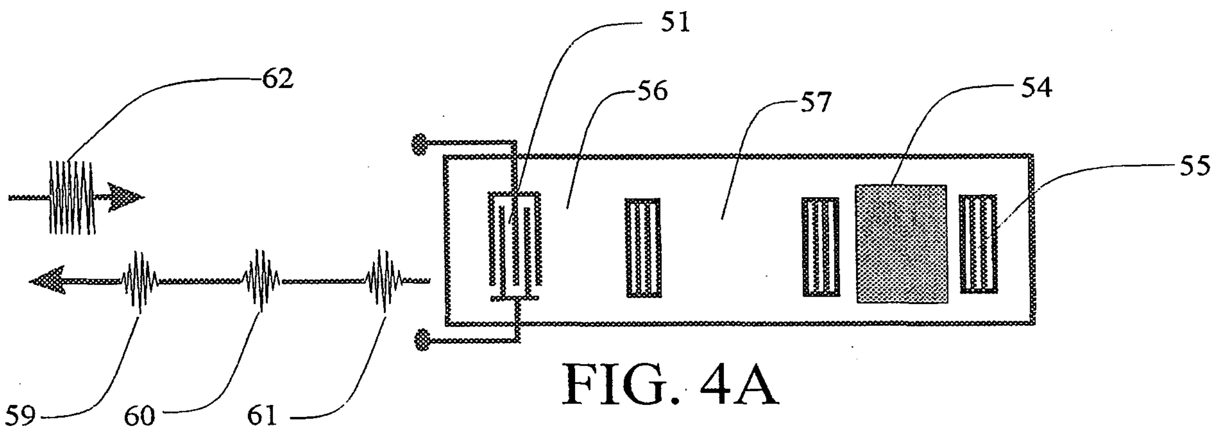


FIG. 4A

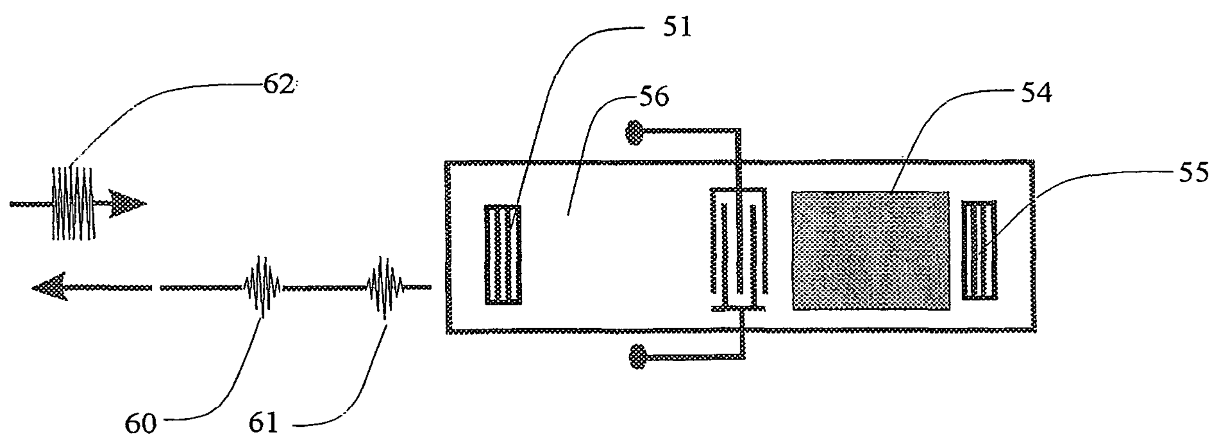


FIG. 4B

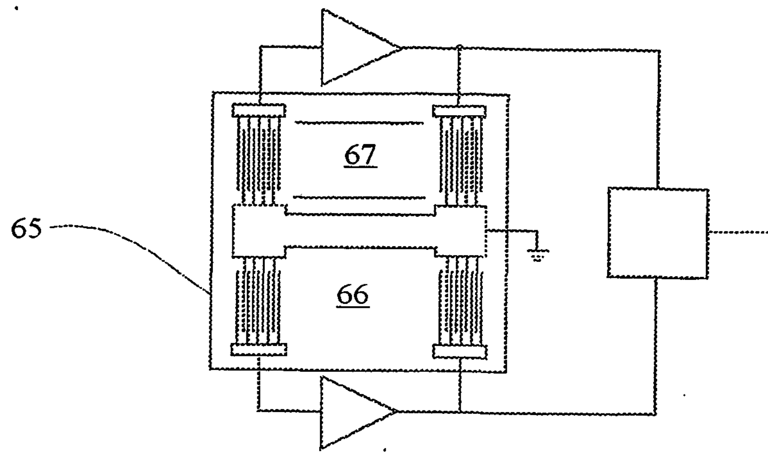


FIG. 5B

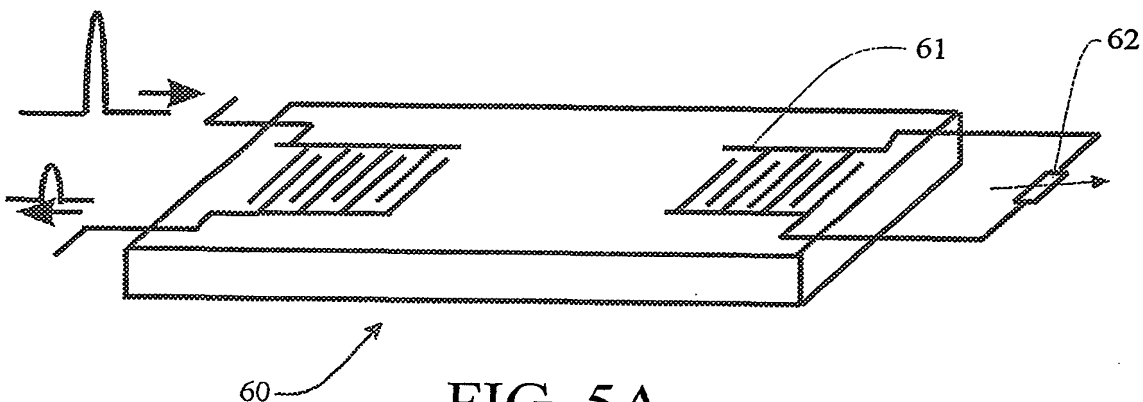


FIG. 5A

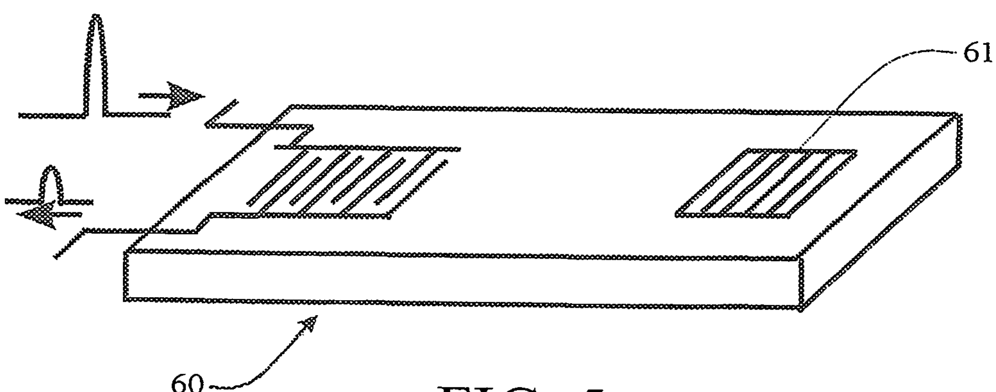


FIG. 5

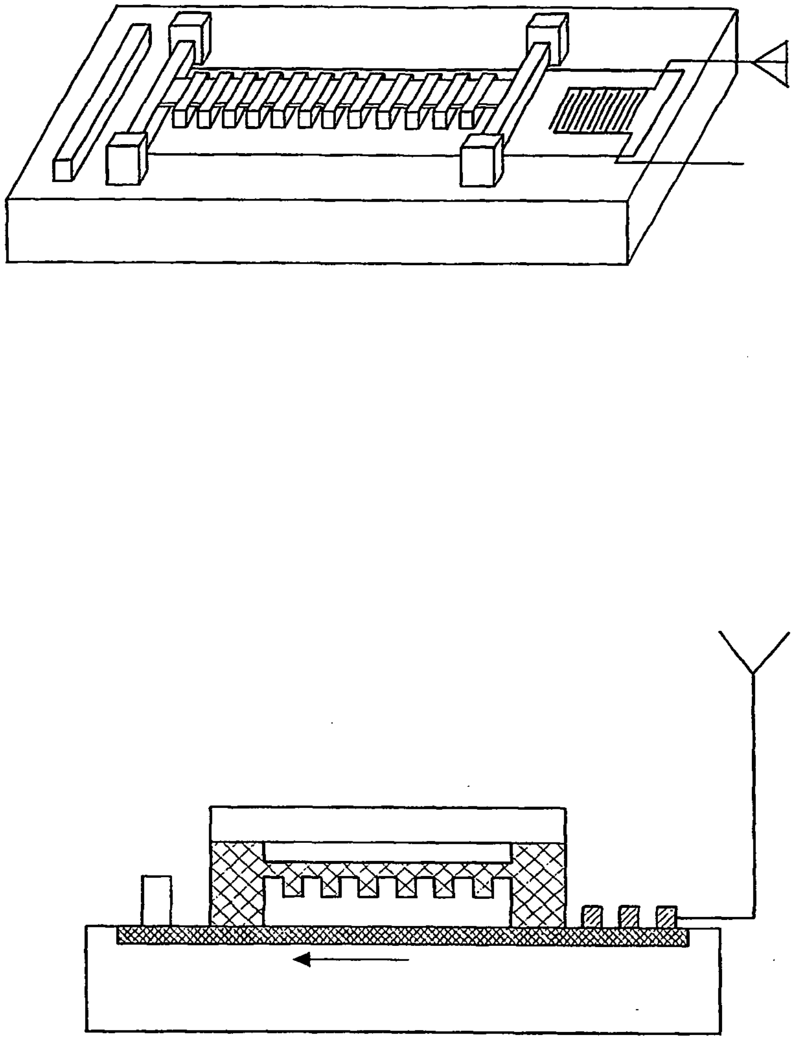


FIG. 6

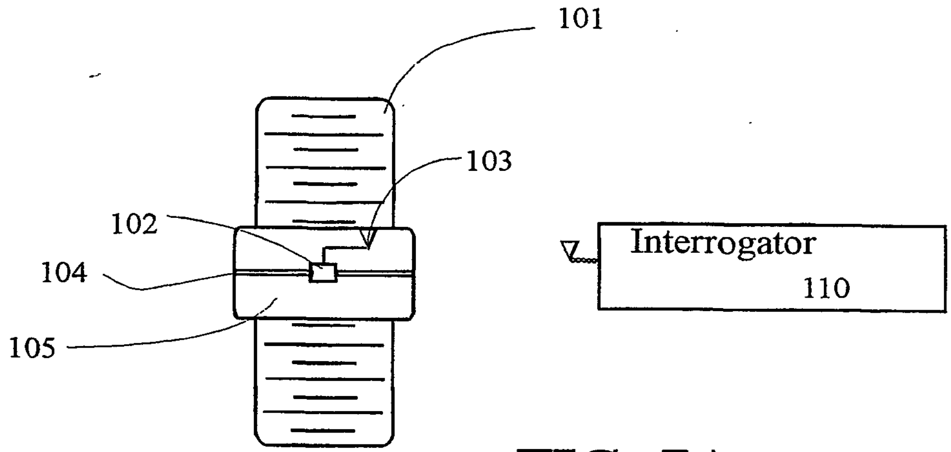


FIG. 7A

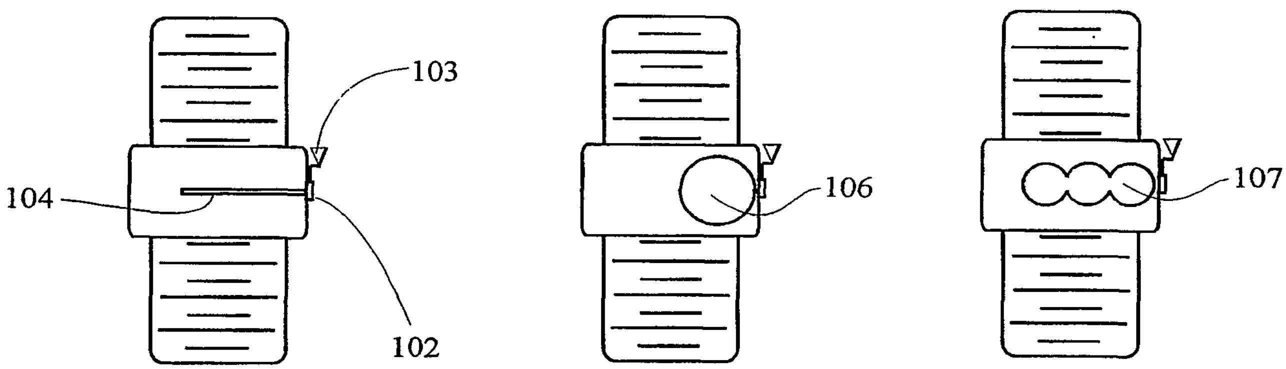


FIG. 7B

FIG. 7C

FIG. 7D

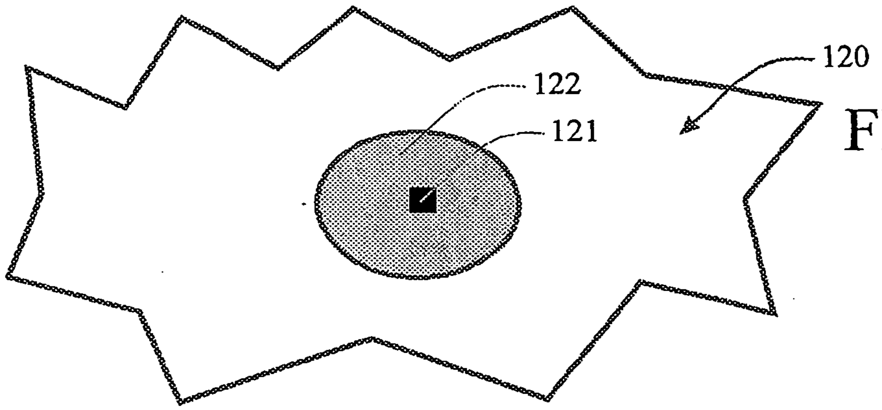


FIG. 8A

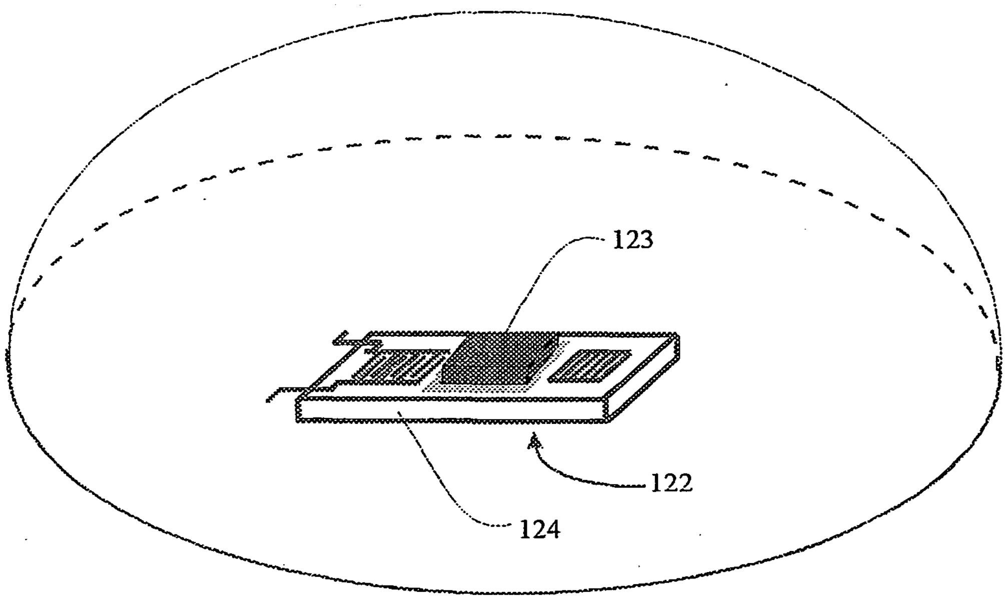


FIG. 8B

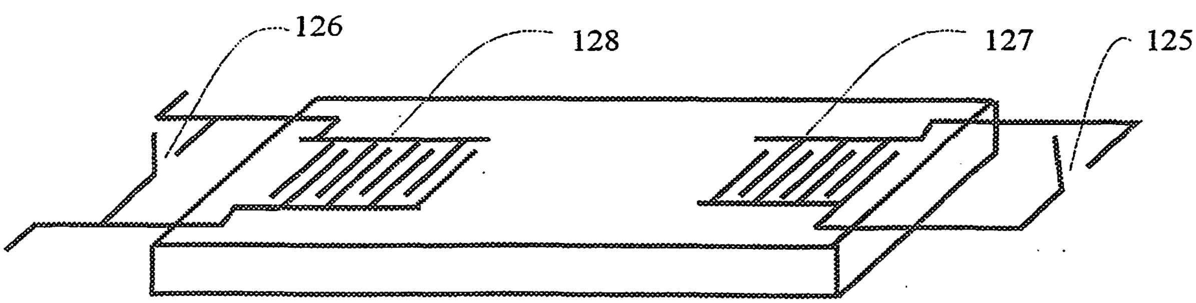


FIG. 8C

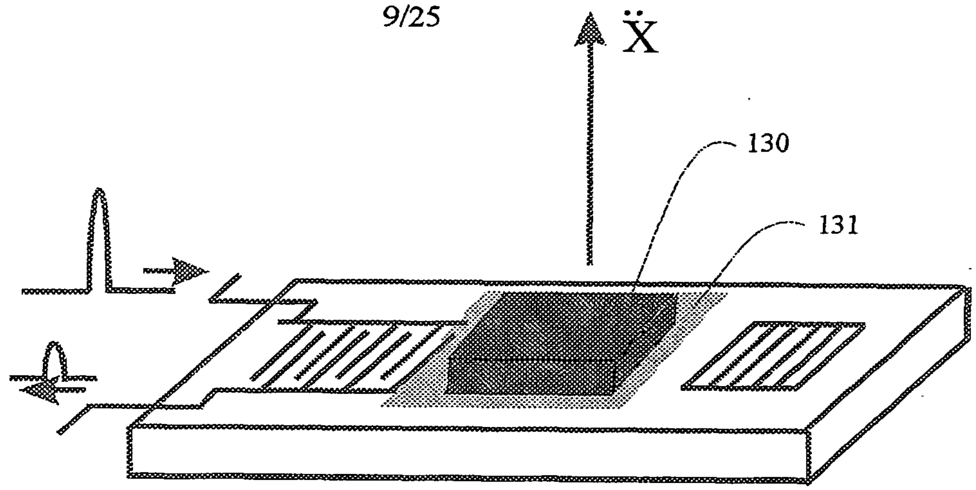


FIG. 9A

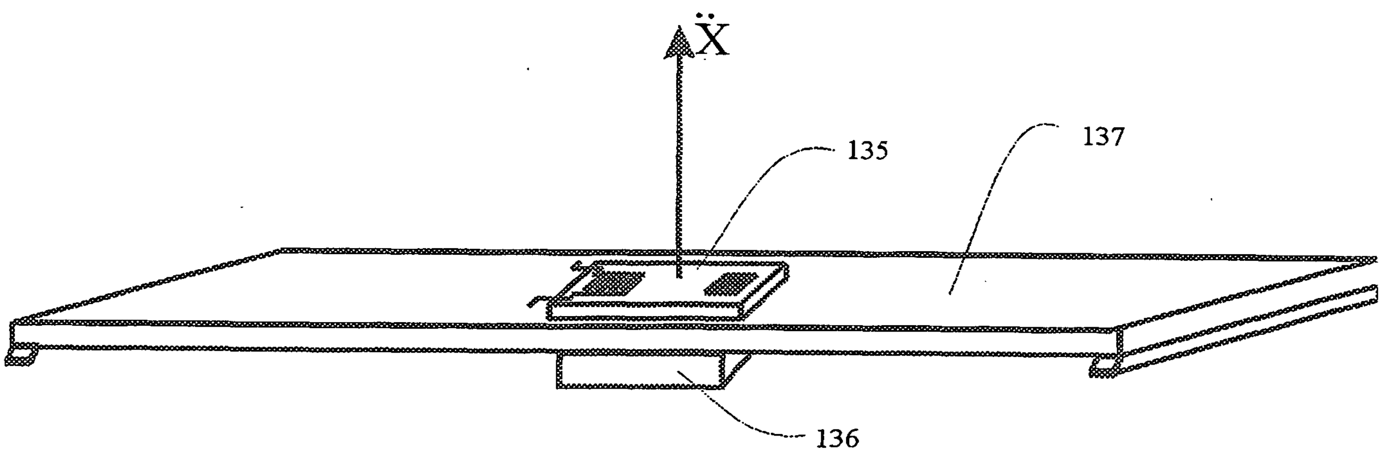


FIG. 9B

Prior Art

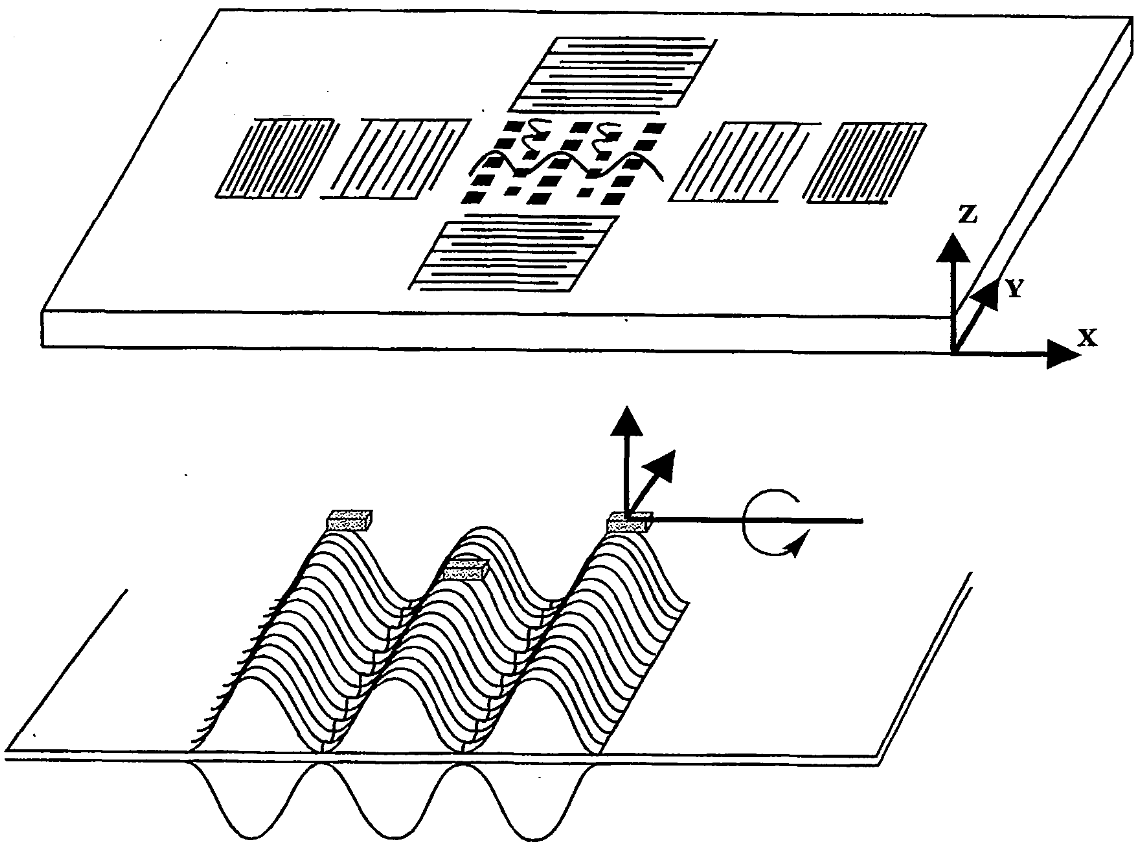


FIG. 10

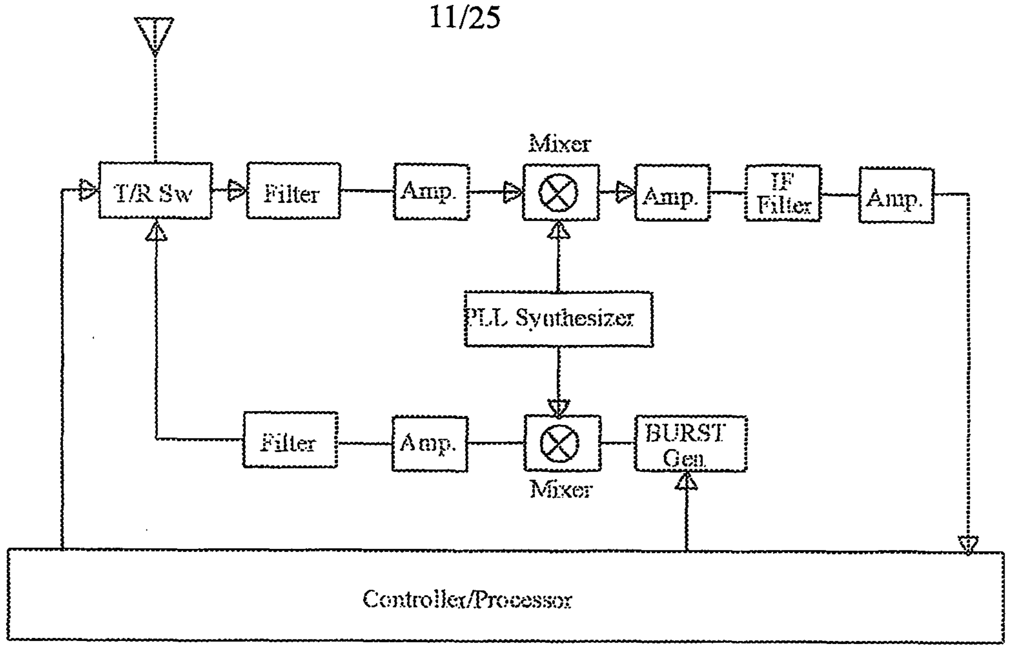


FIG. 11A

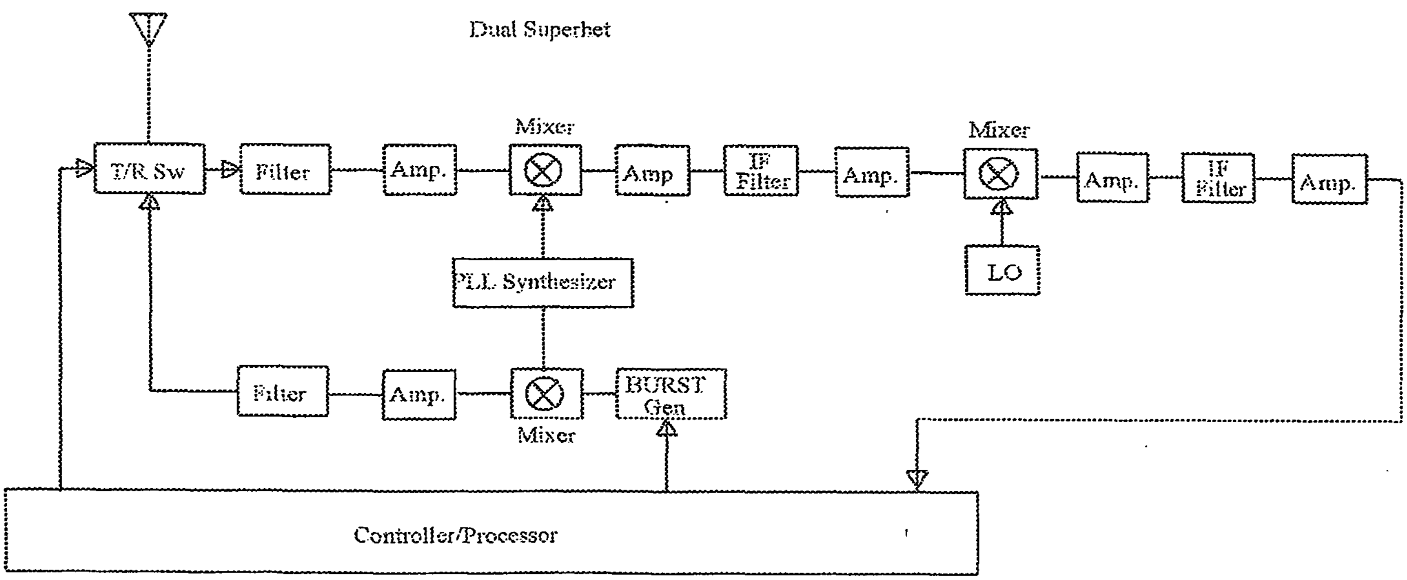
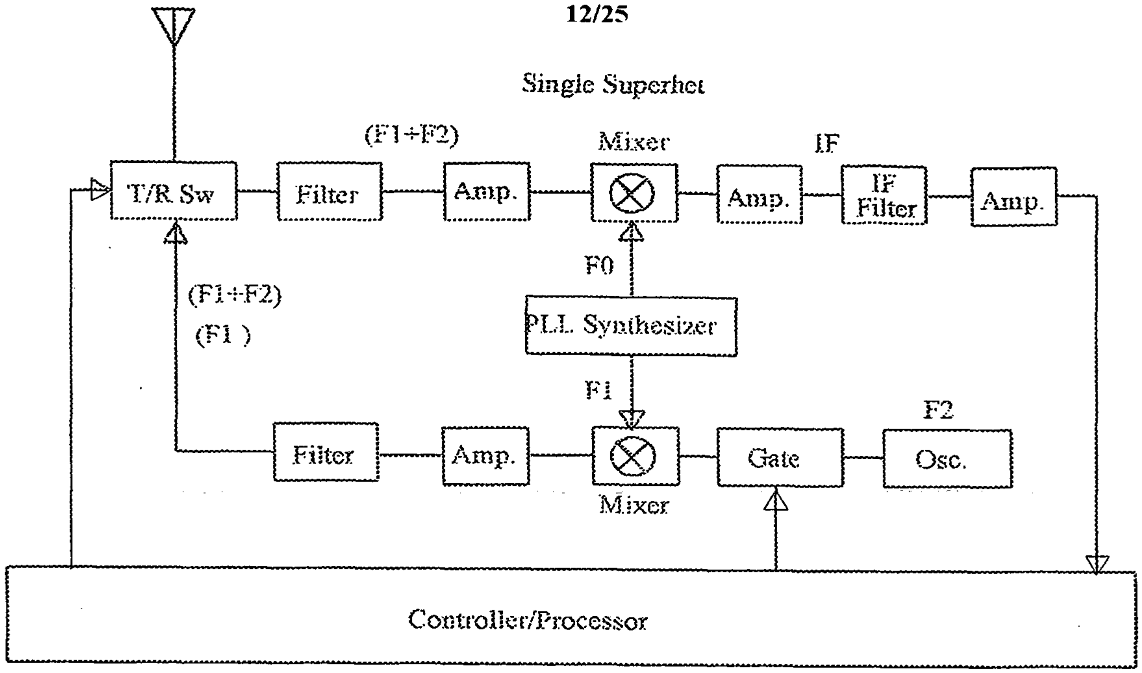


FIG. 11B

Single Superhet



Passive Saw device Freqquency F2

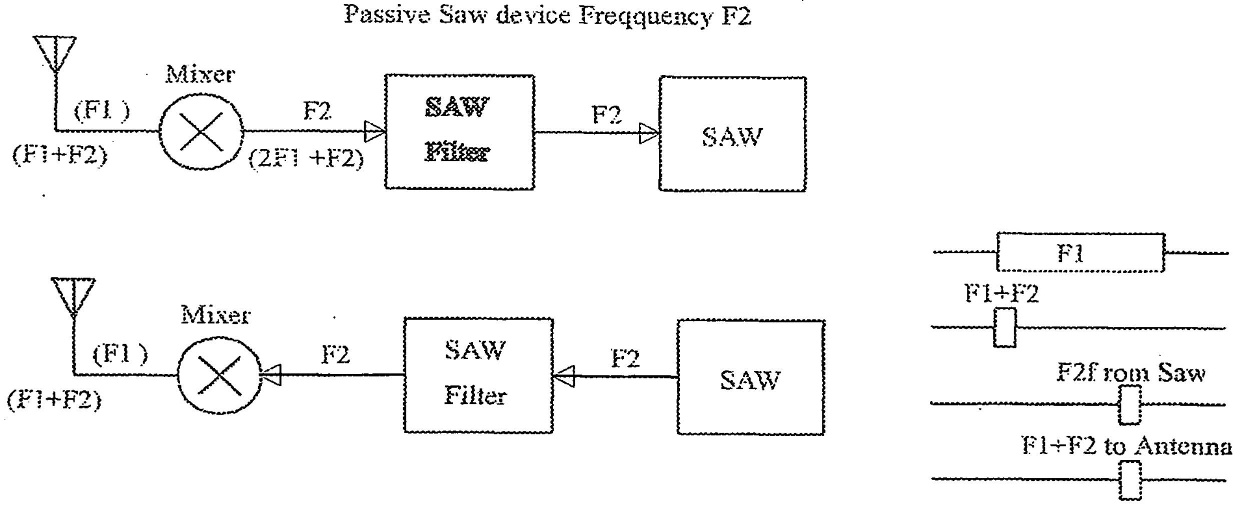


FIG. 11C

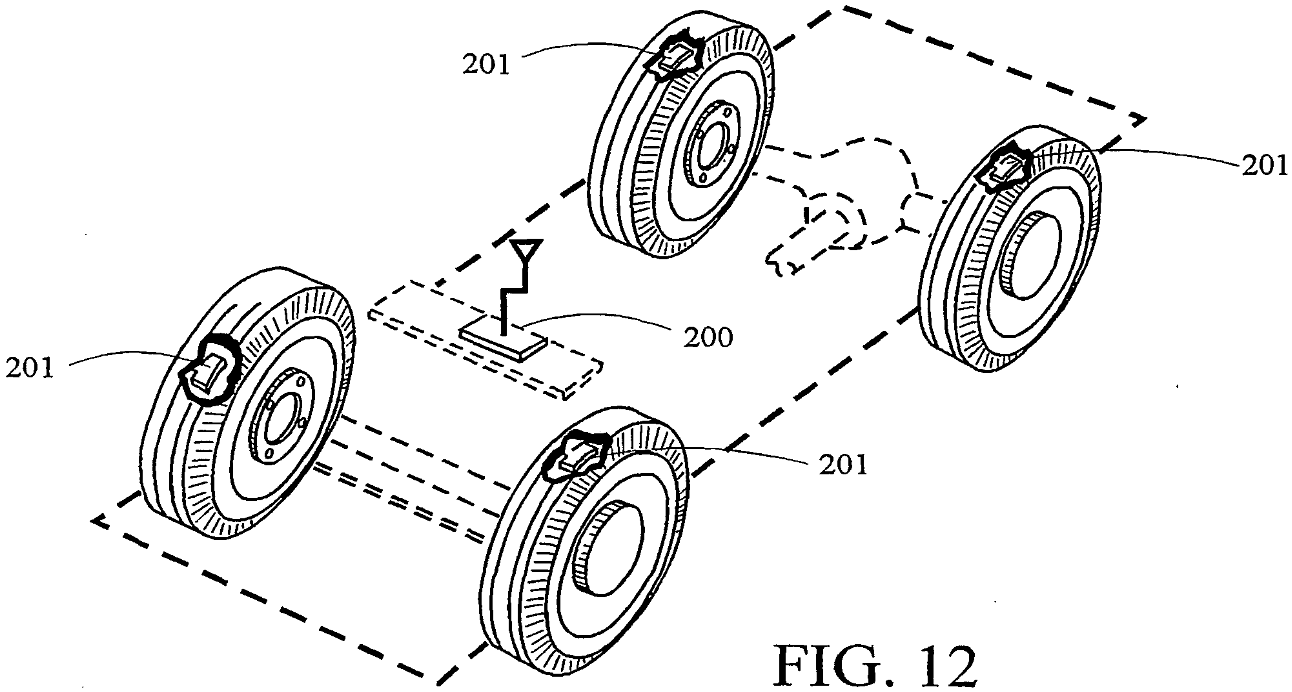


FIG. 12

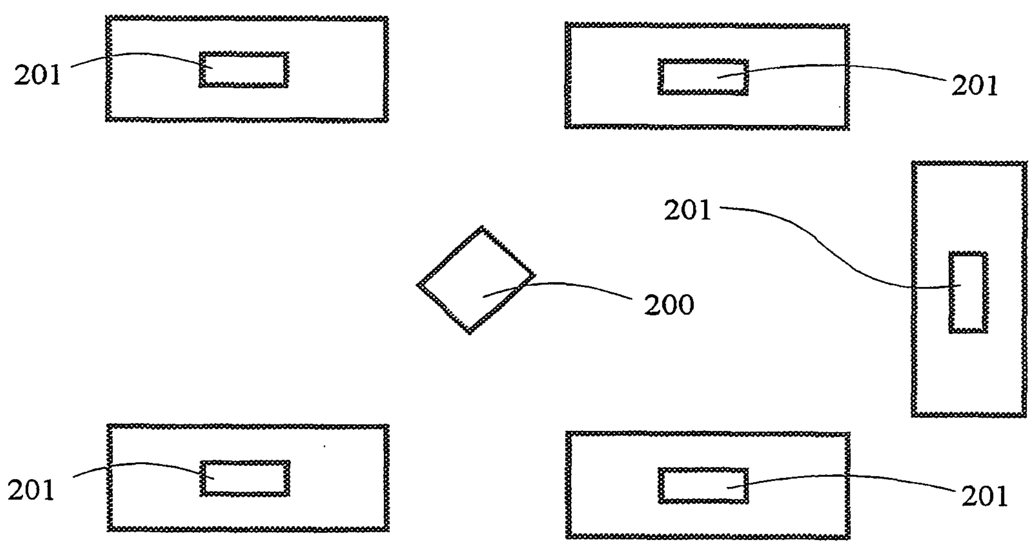


FIG. 12A

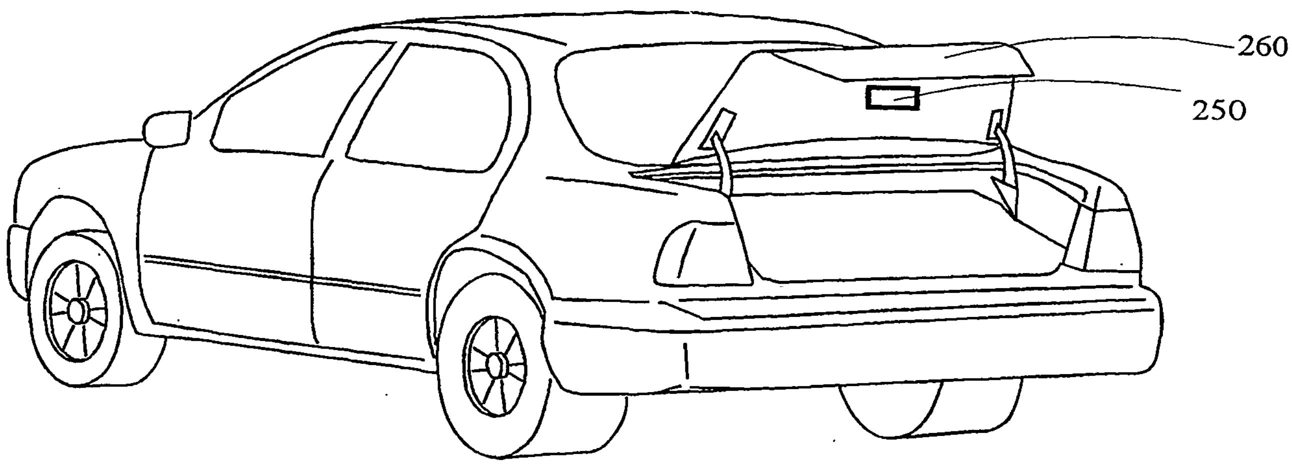


FIG. 13

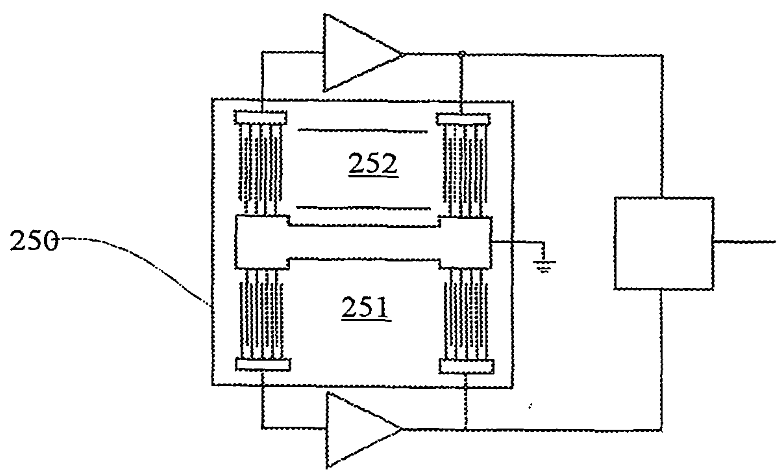


FIG. 13A

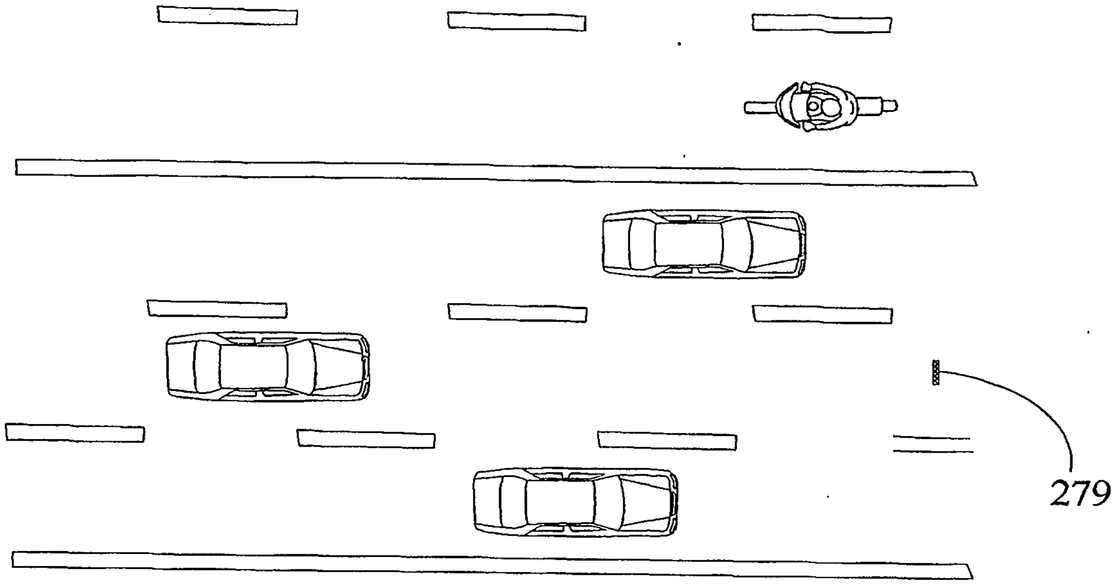


FIG. 14

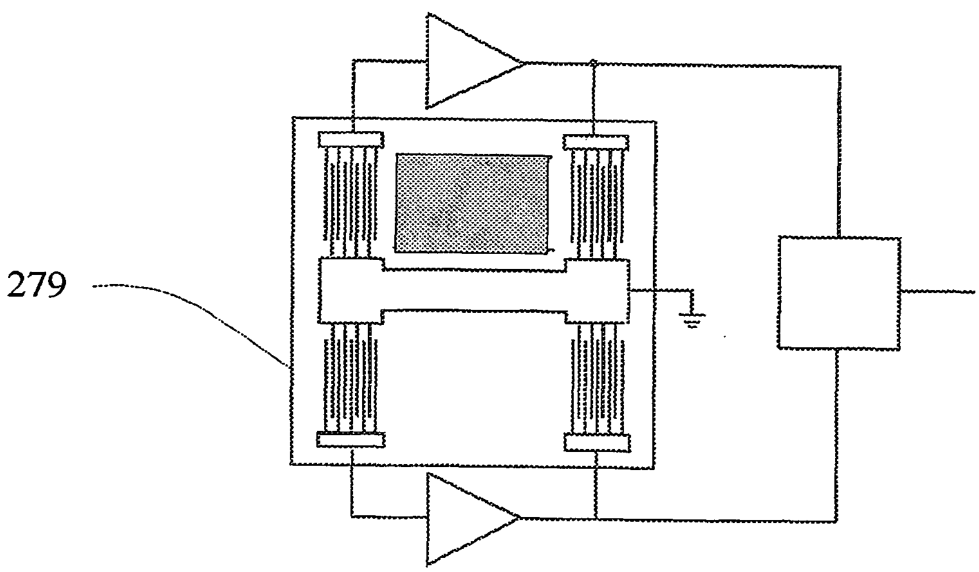


FIG. 14A

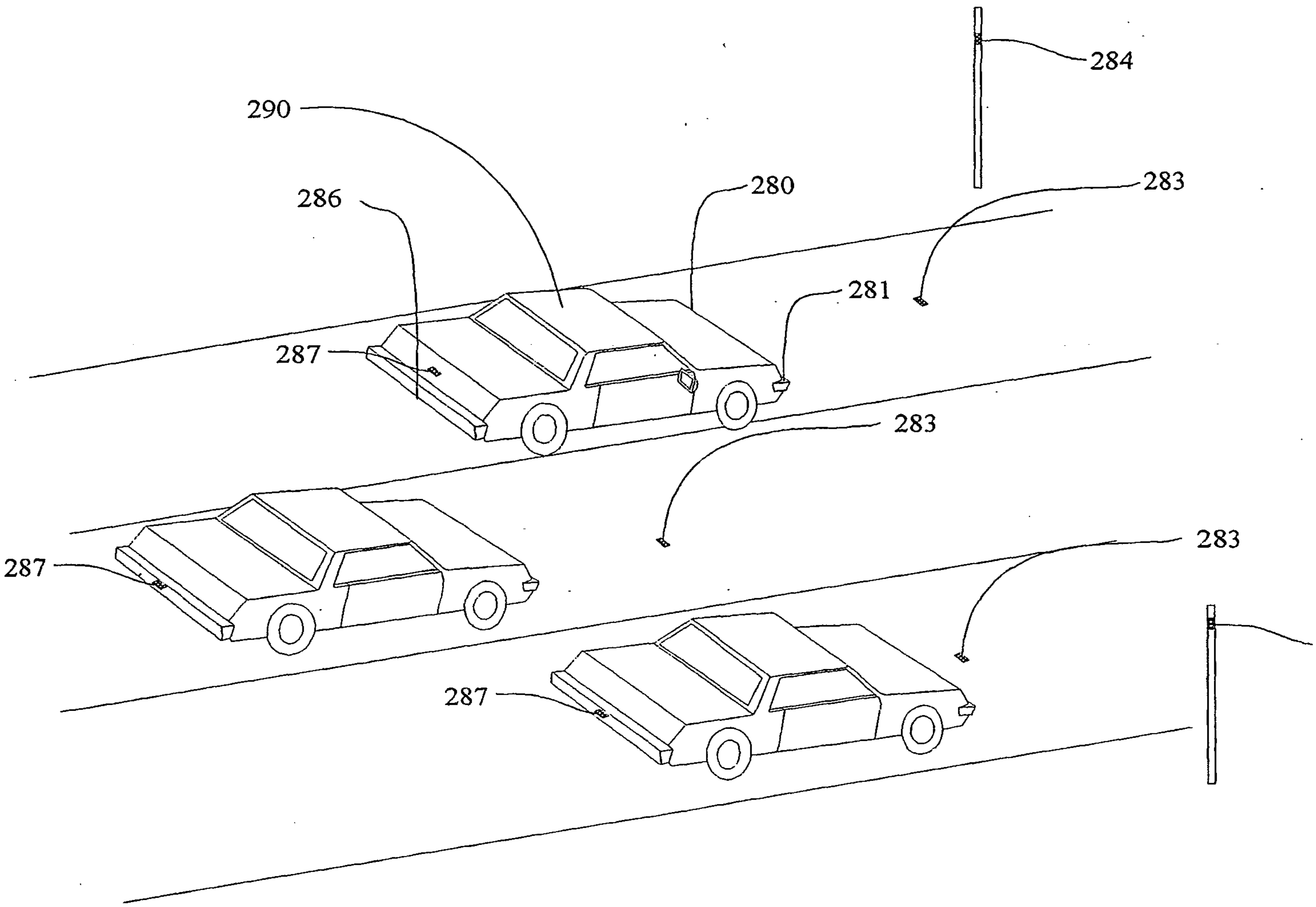


FIG. 15

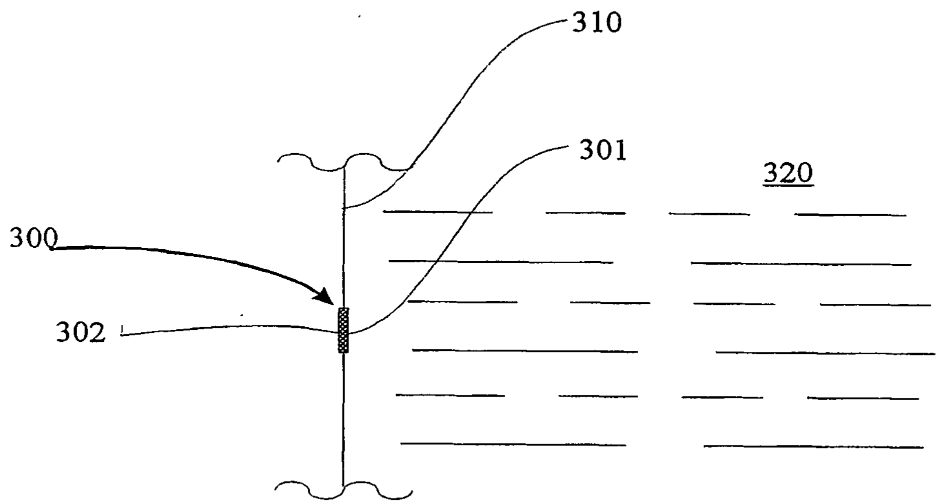


FIG. 16

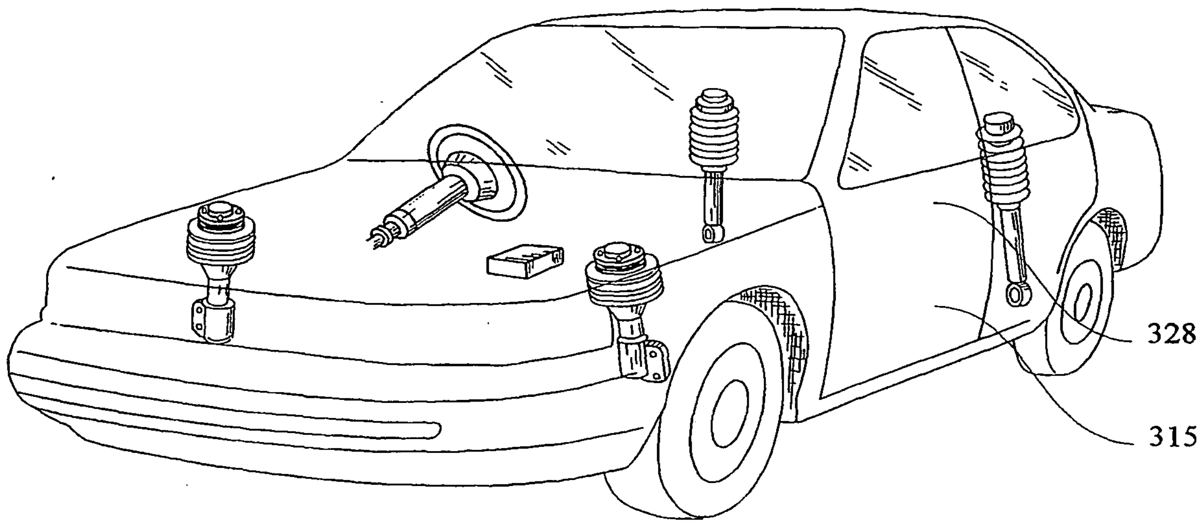


FIG. 17

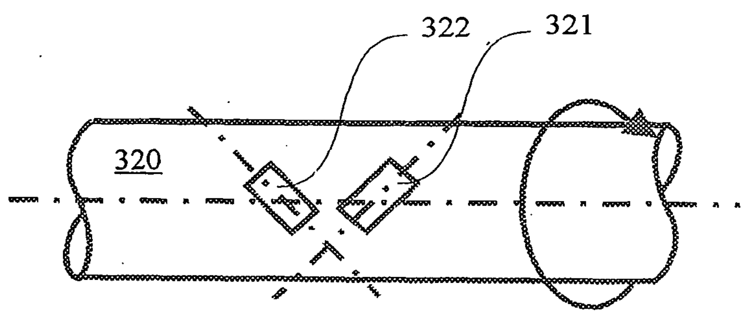


FIG. 17B

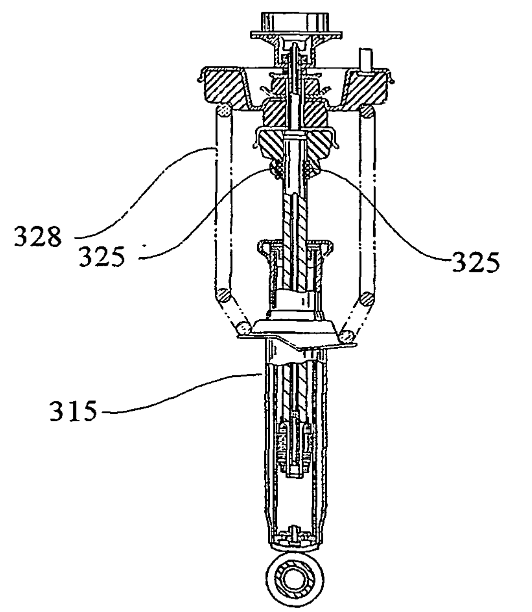


FIG. 17A

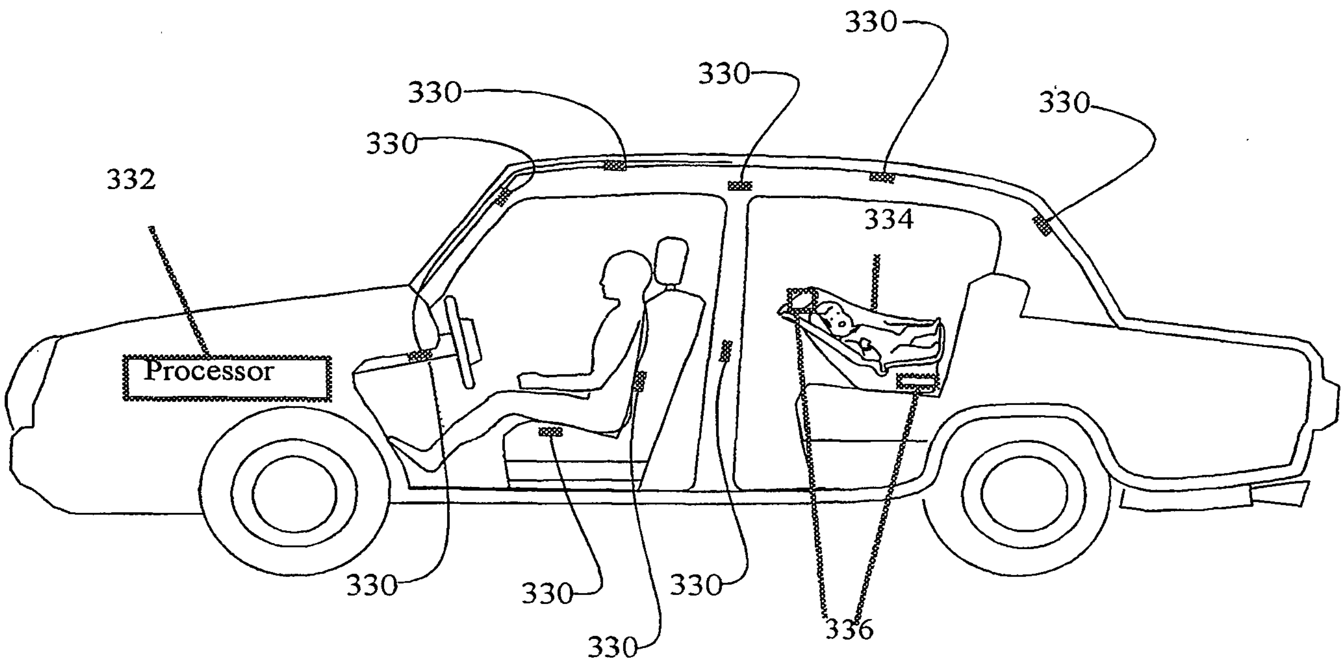


FIG. 18

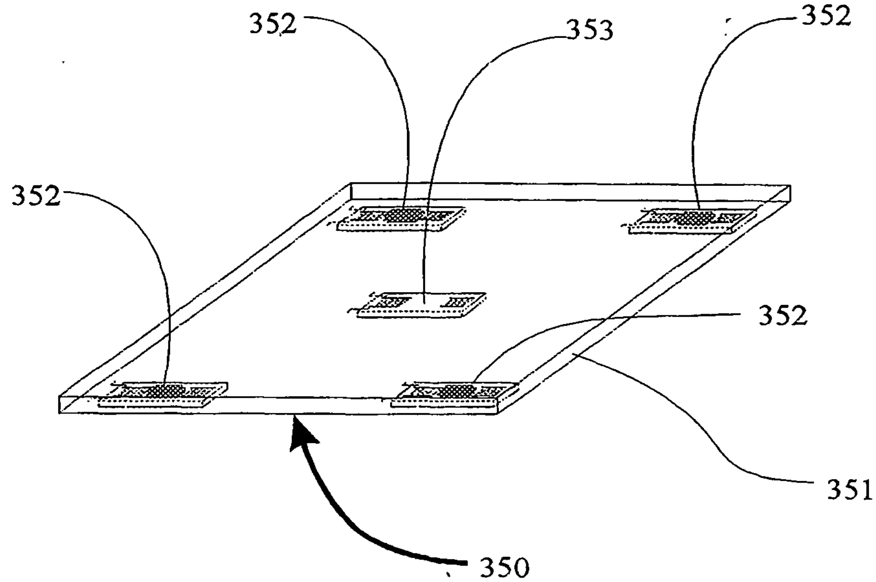


FIG. 19A

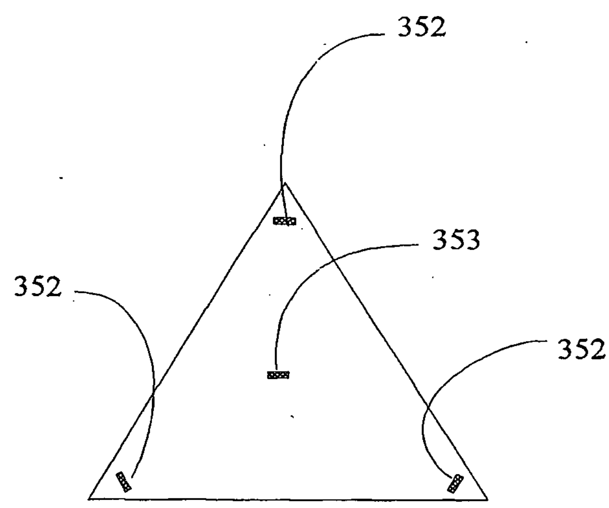


FIG. 19B

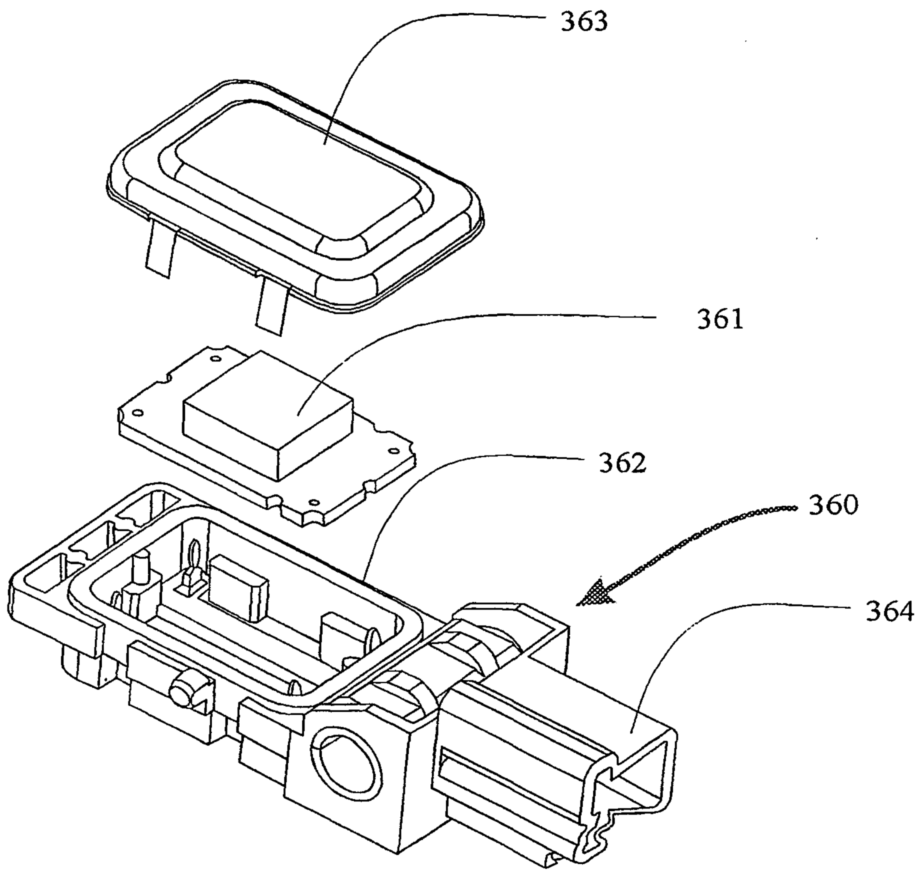


FIG. 20

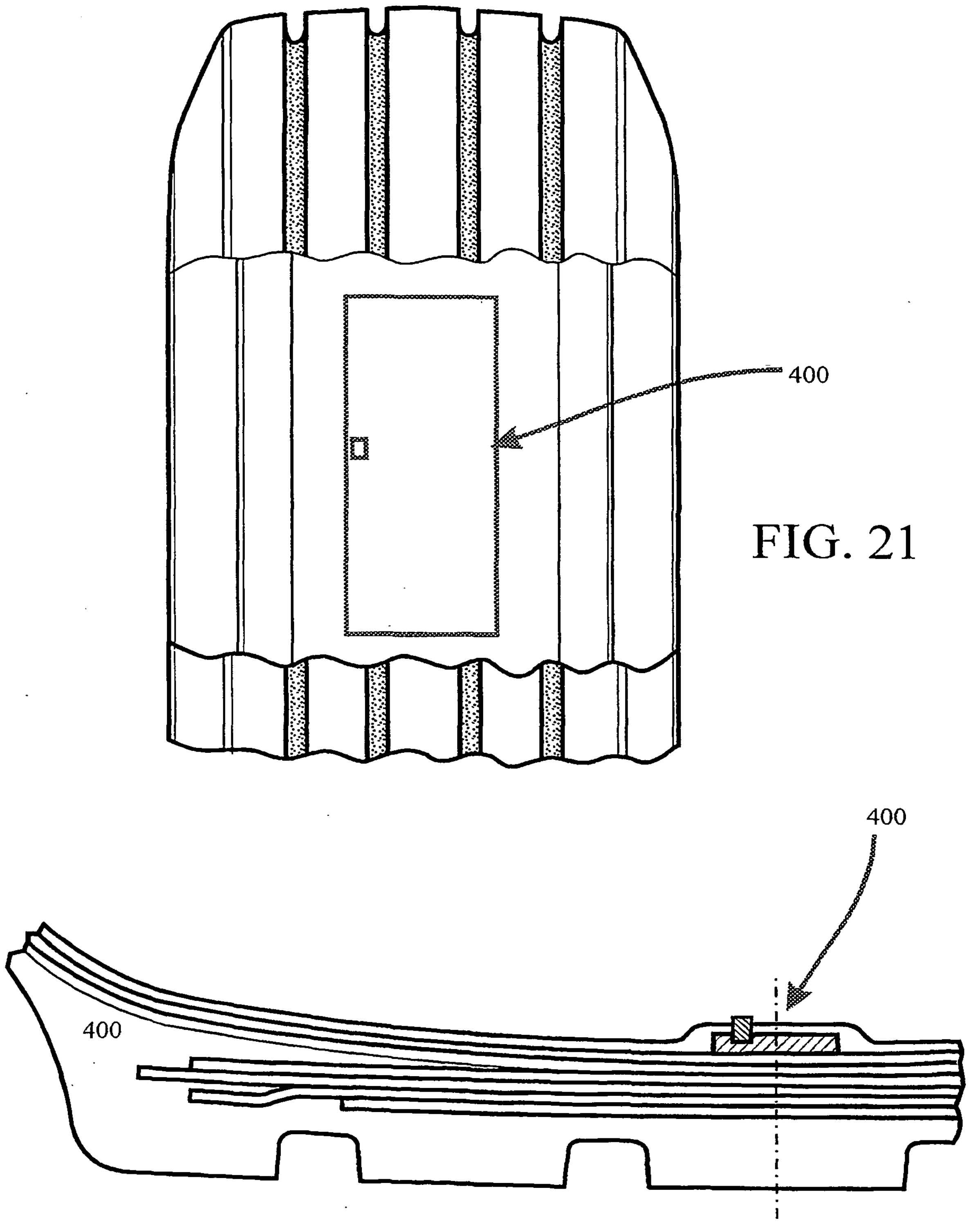


FIG. 21

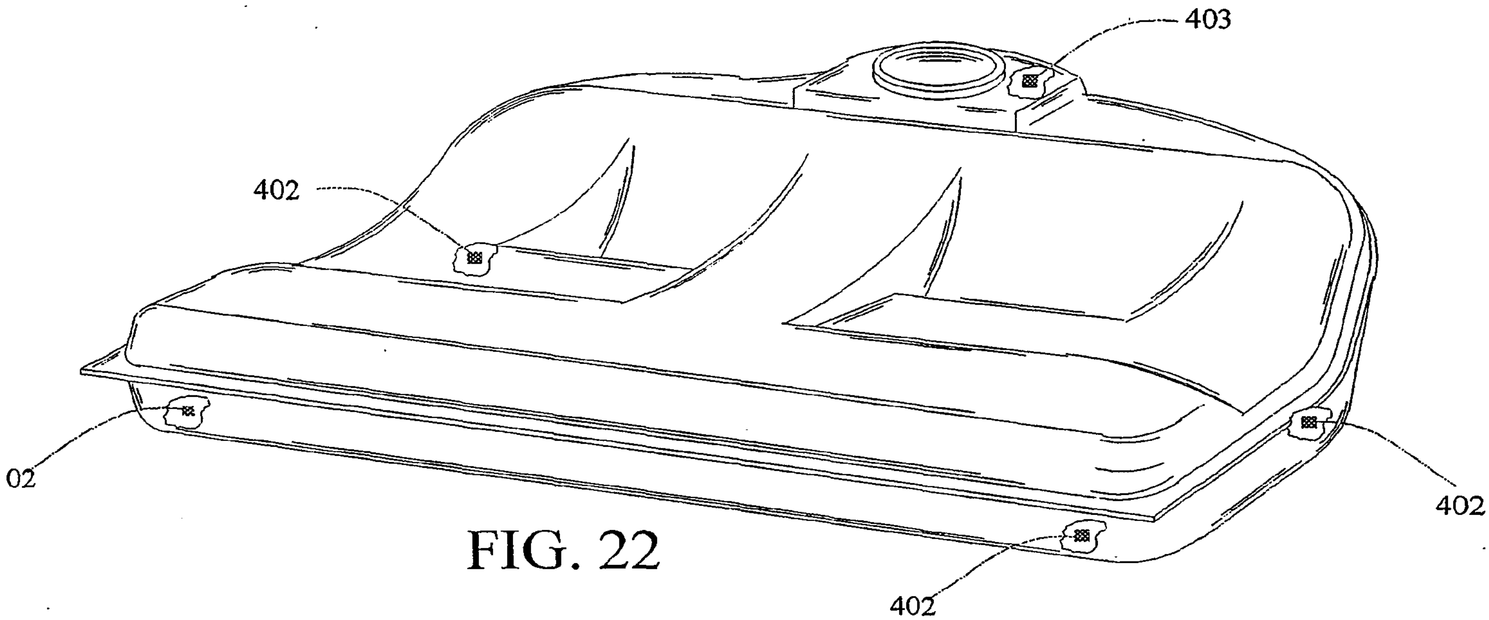


FIG. 22

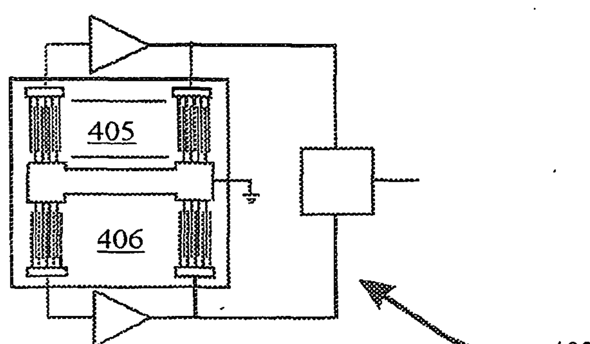


FIG. 22A

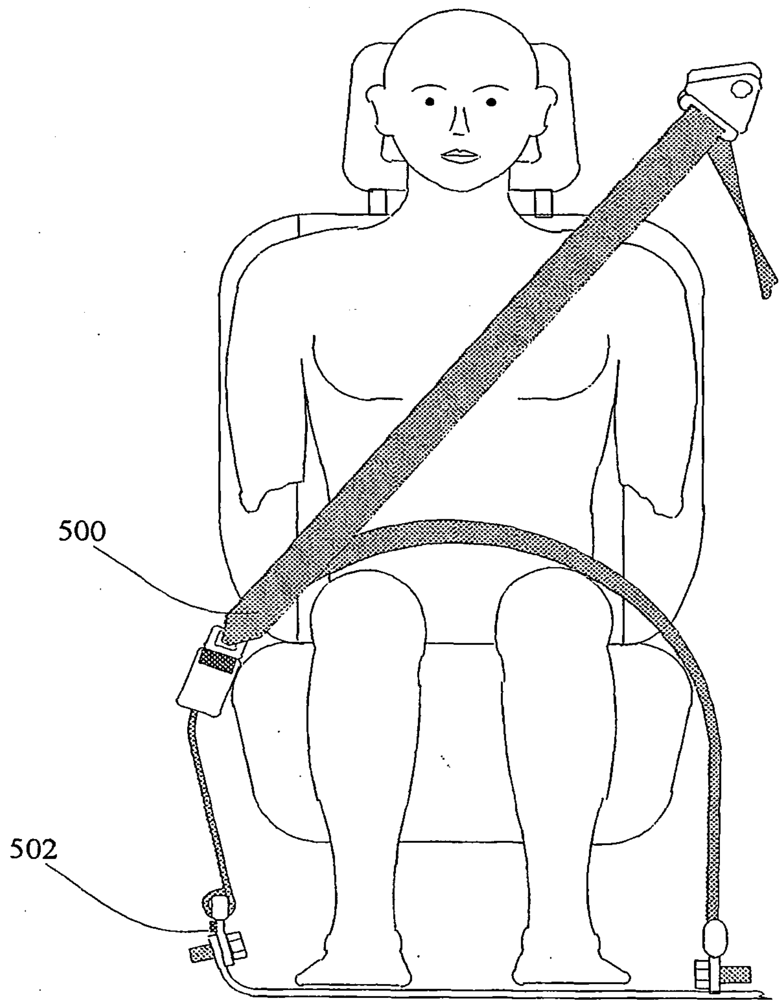


FIG. 23

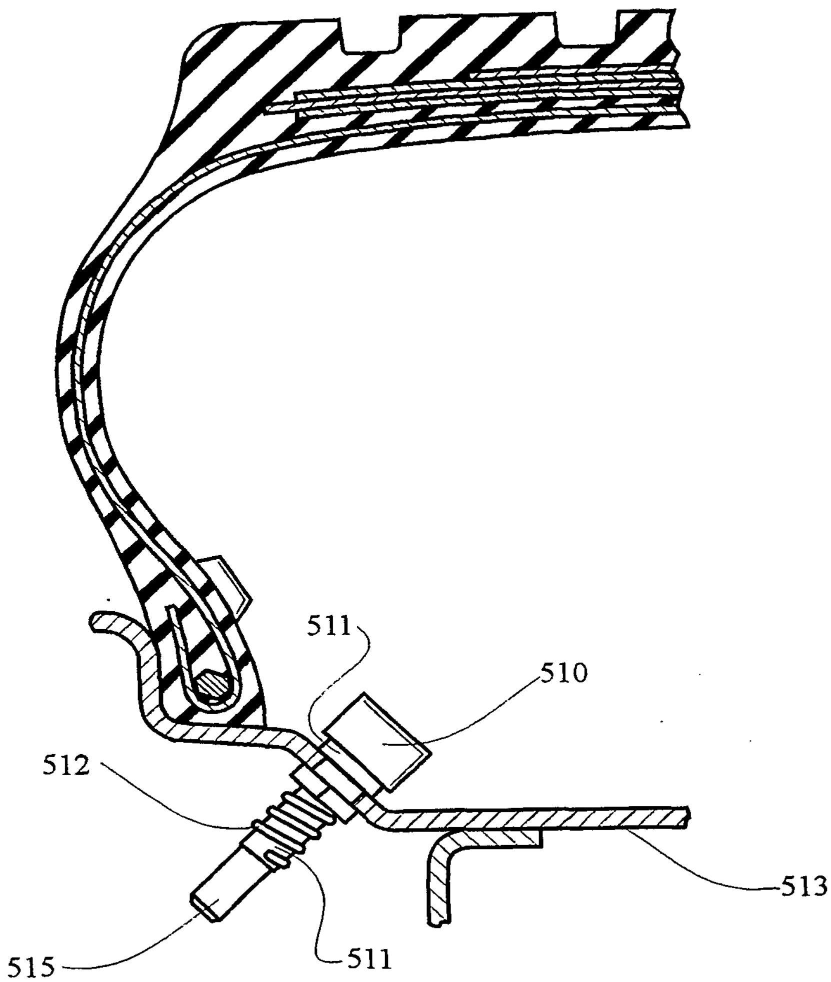


FIG. 24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/28010

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :B60C 23/02
US CL :73/146.5

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/146.5, 146.4, 146.2, 146.8, 703; 340/442, 443, 444

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,853,020 A (WIDNER) 29 December 1998 (29.12.98), entire patent.	1-66
Y	US 5,731,516 A (HANDFIELD et al) 24 March 1998 (24.03.98), entire patent.	1-66
Y	US 5,540,092 A (HANDFIELD et al) 30 June 1996 (30.06.96), entire patent.	1-66

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"B" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

04 NOVEMBER 2001

Date of mailing of the international search report

20 DEC 2001

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

WILLIAM L. OEN

Telephone No. (703) 308-5161